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Water insecurity in the Sinos Basin, RS/Brazil: evidence of risks in current water governance

Julio Cesar Dorneles da Silva
Universidade do Vale do Taquari (Univates) – *Lajeado – RS – Brasil*
ORCID: https://orcid.org/0009-0001-5372-5625

Luís Fernando da Silva Laroque
Universidade do Vale do Taquari (Univates) – Lajeado – RS – Brasil
ORCID: https://orcid.org/0000-0003-1861-4679

Abstract
Water insecurity is on the current agenda of concerns at different scales, from global to local, regarding water governance. The theme gained ground in the final decades of the 20th century and at the beginning of the 21st century. The so-called integrated management of water resources present in the legal and institutional system of water resources in Brazil is linked to the approach known as integrated river basin management (IRBM). The Sinos River Basin (SRB), in the State of Rio Grande do Sul (RS), Brazil, is an area where there was an exponential increase in the demand for water and the release of polluting loads into the basin, in very accentuated processes following the 1970s. This article aims to present evidence of water insecurity experienced in the SRB due to human actions and climate variability in the territory. The research methodology in terms of objective is exploratory, in terms of technical procedures it is bibliographic and documentary and is characterized as qualitative research in the field of human sciences and applied social sciences. The research brings together evidence of impacts generated by human actions and extreme weather events that exposed water insecurity in the study basin. The findings in this SRB case study clearly demonstrate that RS's water resources management system requires governance improvements in order to minimize environmental, social and economic impacts.

Keywords: Rio dos Sinos Hydrographic Basin. Water insecurity. Water governance. Climate changes.

Insegurança hídrica na Bacia do Sinos, RS/Brasil: evidências dos riscos na atual governança da água

Resumo
A insegurança hídrica está na agenda atual das preocupações em diferentes escalas, do global ao local, acerca da governança da água. A temática ganhou espaço nas décadas finais

do século XX e nesse princípio de século XXI. A chamada gestão integrada de recursos hídricos presente no ordenamento jurídico e institucional dos recursos hídricos no Brasil está vinculada à abordagem conhecida como gestão integrada de bacia hidrográfica (GIBH). A bacia hidrográfica do Rio dos Sinos (BHRS), no Estado do Rio Grande do Sul (RS), Brasil, é um espaço em que se deu um aumento exponencial da demanda por água e de lançamento de cargas poluentes na bacia, em processos muito acentuados a partir da década de 1970. Este artigo objetiva apresentar evidências da insegurança hídrica vivenciada na BHRS em razão das ações antrópicas e da variabilidade climática no território. A metodologia da pesquisa quanto ao objetivo é exploratória, quanto aos procedimentos técnicos é bibliográfica e documental e se caracteriza como uma pesquisa qualitativa no campo das ciências humanas e ciências sociais aplicadas. A pesquisa reúne evidências de impactos gerados por ações antrópicas e por eventos climáticos extremos que expuseram a insegurança hídrica na bacia de estudo. Os achados neste estudo de caso da BHRS demonstram claramente que o sistema de gestão de recursos hídricos do RS necessita melhorias de governança a fim de minimizar-se os impactos ambientais, sociais e econômicos.

Palavras-Chave: Bacia Hidrográfica do Rio dos Sinos. Insegurança hídrica. Governança da água. Mudanças climáticas.

Inseguridad hídrica en la Cuenca de Sinos, RS/Brasil: evidencia de riesgos en la actual gobernanza del agua

Resumen

La inseguridad hídrica está en la agenda actual de preocupaciones a diferentes escalas, desde la global hasta la local, en relación con la gobernanza del agua. El tema ganó terreno en las últimas décadas del siglo XX y principios del XXI. La llamada gestión integrada de los recursos hídricos presente en el sistema legal e institucional de los recursos hídricos en Brasil está vinculada al enfoque conocido como gestión integrada de cuencas hidrográficas (GICH). La cuenca hidrográfica del Río dos Sinos (CHRS), en el Estado de Rio Grande do Sul (RS), Brasil, es una zona donde se produjo un aumento exponencial de la demanda de agua y de la liberación de cargas contaminantes en la cuenca, en procesos muy acentuados tras la Década de 1970. Este artículo tiene como objetivo presentar evidencias de la inseguridad hídrica vivida en la CHRS debido a las acciones humanas y a la variabilidad climática en el territorio. La metodología de investigación en cuanto a objetivo es exploratoria, en cuanto a procedimientos técnicos es bibliográfica y documental y se caracteriza por ser una investigación cualitativa en el campo de las ciencias humanas y las ciencias sociales aplicadas. La investigación reúne evidencia de impactos generados por acciones humanas y eventos climáticos extremos que expusieron la inseguridad hídrica en la cuenca de estudio. Los hallazgos de este estudio de caso de CHRS demuestran claramente que el sistema de gestión de recursos hídricos de RS requiere mejoras de gobernanza para minimizar los impactos ambientales, sociales y económicos.

Palabras clave: Cuenca Hidrográfica del Río dos Sinos. Inseguridad hídrica. Gobernanza del agua. Cambios climáticos.

1 Introduction

A new paradigm for water resource management characterized the last decade of the 20th century and these first decades of the 21st century (Gleick *et al*., 2018; Hooper, 2005). However, throughout the 20th century, concerns about water management were subordinated to concepts of political and economic development

that were priorities. According to Gleick *et al*. (2018), the management of natural resources and water resources emerged as a process for allocating these resources to meet human demands through environmental interventions that did not necessarily consider high costs, including and especially environmental ones.

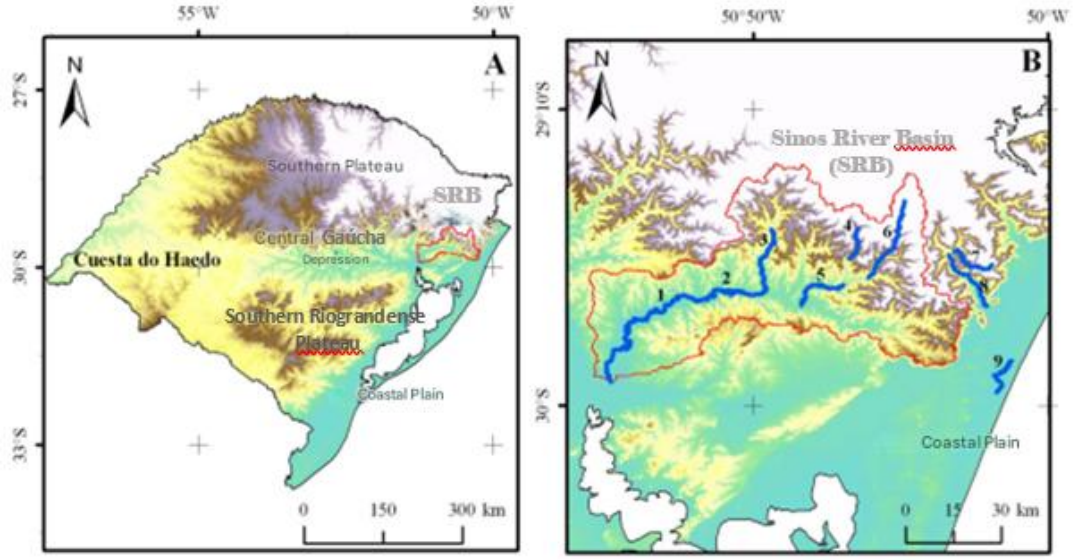
Gleick *et al.* (2018) characterized water resource management in the 20th century as a policy of building infrastructure aimed at meeting human water needs and other uses, without necessarily considering costs and environmental risks. Gleick *et al.* (2018) and Hooper (2005) highlighted the need for a new transition approach to a soft path that considers community, local, and regional scales, decentralization, equity, technological innovations with efficiency gains, and environmental protection.

In this sense, Hooper (2005) identified the contribution of geographic research and how it was influenced by the work of environmental psychologists, ecologists, and economists, all experts in natural resources. These researchers, through interdisciplinary work, formed the basis of a modern paradigm. This paradigm sought to consider natural resource management from an interdisciplinary perspective, and on this new paradigm, governance, or Integrated Watershed Management (IWBM), was built.

The IWBM integrated the human-environmental approach of geography in an interdisciplinary manner, influenced by the work of ecologists, psychologists, and environmental economists, creating a new paradigm for water governance (Hooper, 2005). The need to address the issue of watershed governance is related to the difficulty of effective water management—that is, managing the capture, treatment, distribution, and multiple uses of this natural resource. It also addresses water security, its risks in terms of both quantity and quality, and, therefore, the preservation of ecosystems (Di Mauro; Mageste; Lemes, 2017; Santos, J.V., 2023; Silva, 2020; Tucci, 2023).

This article presents evidence of water insecurity in the Sinos River Basin (SRB) due to anthropogenic actions and climate variability. To this end, we address the issue of water security related to water management by watershed, using as a case study the Sinos River Basin (SRB), which is located in the northeastern part of the state of Rio Grande do Sul, RS, Brazil, and is part of the Guaíba river basin (Figure 1).

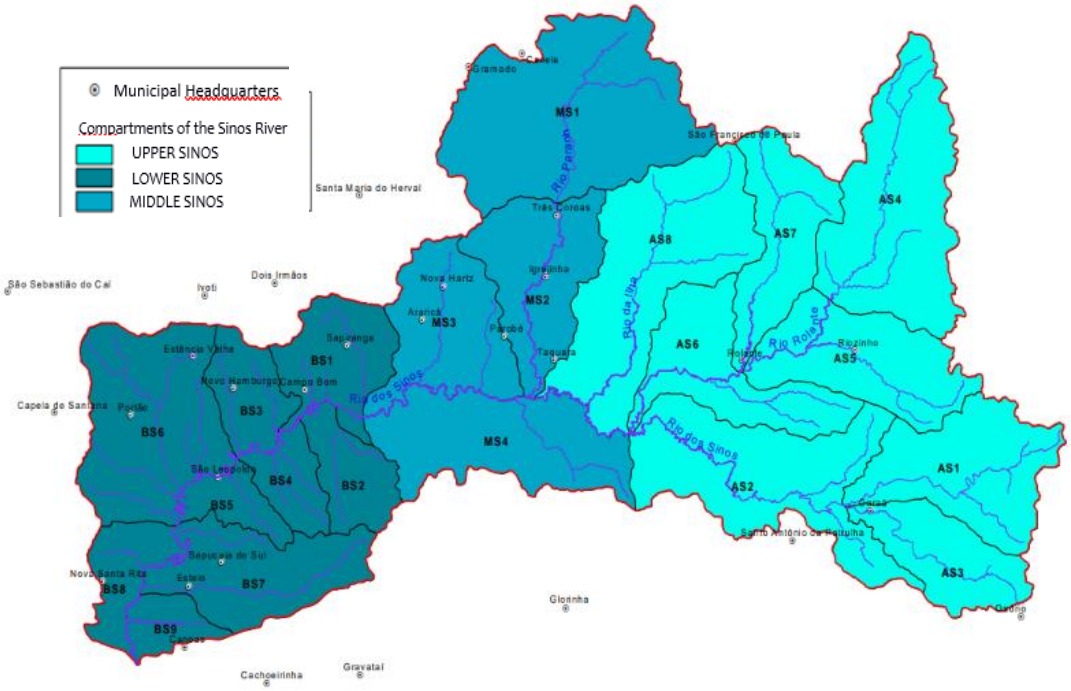
Figure 1: Sinos River Basin (RBS) – location



Source: Adapted from Brubacher; *et al.*, 2012, p. 383.

The main water bodies of the SRB are the Rolante, Ilha, Paranhana, and Sinos rivers, the first three tributaries of the Sinos (Figure 2). It covers an area of 3,694 km² and had an estimated population of 1,447,678 inhabitants in 2020. 95% of this population lives in urban areas, with the highest demographic concentration in the Low Sinos compartment. The SRB covers, in whole or in part, the area of 30 municipalities (Comitesinos, 2025a; Sema, 2025; Silva, 2020).

Figure 2: BHRS, compartments: Upper, Middle and Lower Sinos



Source: Plano de bacia – Relatório Final RT1 (Comitesinos; Profill, 2014a, p. 244).

The SRB was chosen as a case study for this research because it is among the ten most polluted basins in Brazil (Bassan; Silva, 2019; Hinata; *et al*., 2023; Reinholz, 2022; Silva, 2020; Soldera, 2023), considering the loads of domestic sewage and industrial effluents that are discharged into its watercourses. This is due to the strong presence of industrial activities from various economic sectors and the sharp population growth since the 1970s, without coverage by advanced domestic sewage treatment (Silva, 2020).

Since the early 1970s, the BHRS territory has undergone a process of accelerated urbanization in the basin's three major compartments: Upper Sinos, which corresponds to the highlands; Middle Sinos (middle lands); and Lower Sinos, corresponding to the lowlands, the final stretch of the basin. The Middle and Lower Sinos compartments present the highest rates of human density and the presence of industrial activities (Comitesinos, 2025a; Comitesinos; Profill, 2014b, 2014c; Pró-Sinos, 2014; Silva, 2020; SPGG, 2024a). This worsens water insecurity associated with other factors that generate water insecurity, such as: the dynamics of the Sinos flow rates, with recurring water deficits in summers (Sema, 2017); the high demand for raw water withdrawal for water supply systems (SAA); competition from water withdrawal for irrigated rice cultivation, present in the three compartments of the basin (Comitesinos; Profill, 2014b, 2014c; Pró-Sinos, 2014; Silva, 2020); the dependence on water transposition from the Caí River basin to the Sinos, through the existing electricity generation system (Sema, 2017); the recurrence of climatic events associated with scarcity (Castro; A. L. A.; *et al*., 2019) or excess of water (SPGG, 2024b, 2024c) and, last but not least: management failures (Castro, C.N., 2022; Silva, 2020; Tucci, 2023).

Currently, domestic sewage accounts for an even greater proportion of industrial effluents, as under pressure from the environmental movement of the 1980s and 1990s, the industrial sector advanced in the implementation of effective treatment systems (Bassan; Silva, 2019; Silva, 2020). However, the rate of domestic sewage treatment has shown almost negligible growth across the BHRS (Gonçalves, 2025; Silva, 2020) over the last 37 years, taking as a reference the year of creation of the Sinos River Basin Committee – Comitesinos, on March 31, 1988 (Comitesinos, 2025a, 2025b).

2 Applied methodology

The research methodology is exploratory in terms of objective, and bibliographical and documentary in terms of technical procedures. It is characterized as qualitative research in the field of human sciences and applied social sciences (Gil, 2008; Laville; Dionne, 1999; Marconi; Lakatos, 2017). This research aims to contribute knowledge capable of promoting the improvement of the existing water governance system in RS, through a possible reduction of risks to water security through improvements in water governance (Silva, 2020; Tucci, 2023).

This is a case study of the Sinos River Basin (SRB, RS/Brazil), which drew on the analysis of primary sources (documents) from Comitesinos and other sources related to the research topic. Among these, the following stand out:

- The Sinos Plan (Pró-Sinos, 2014);
- The Sinos Basin Plan (Comitesinos; Profill, 2014a, 2014b, 2014c);

• The technical study by the Water Resources Granting and Oversight Division of SEMA RS on the water deficit in the BHRS (Sema, 2017), supplemented by technical note No. 002/2024, dated December 26, 2024, produced by the Water Resources Planning and Management Division of the Department of Water Resources and Sanitation (Sema, 2024);

• The Metropolitan Flood Protection Plan (Metroplan, 2018);

• Official publications presenting the structure of the Integrated Water Resources Management System (IWRMS) of RS; • And sources of climatological information, with data and analyses regarding extreme climatological events in RS.

Regarding secondary sources, we used reference works by leading researchers in Portuguese and English on the topic in question, as well as other scientific or technical works specializing in water governance or water resource policy. By adopting the current approach based on the IRBM (Gleick; *et al.,* 2018; Hooper, 2005; Tucci, 2023) as a reference for the study of river basins, we recognized the need to consider water resource governance as a complex process, encompassing the interdependence of the ecosystem's stakeholders, as occurs within a given river basin or set of basins.

Therefore, water resource governance in Rio Grande do Sul (RS) should reflect this characteristic complexity of the existing river basin system (Castro, C. N., 2022; Silva, 2020).

3 Characterization of the Sinos River Basin (SRB)

The SRB can be characterized as a river basin highly impacted by anthropogenic processes within its territory (Comitesinos, 2025a; Silva, 2020). In the current context, in these first decades of the 21st century, as a result of the occupation of the basin's territory, especially through the industrialization and urbanization processes throughout the last century, the set of most serious anthropogenic environmental problems in the SRB territory are identified both by the scientific literature (Bassan; Silva, 2019; Moura, 2016; Hinata; *et. al*.; 2023) and by the Sinos Plan (Pró-Sinos, 2014) and the Sinos Basin Plan (Comitesinos; Profill, 2014a, 2014b, 2014c), such as: the discharge of sewage from domestic sources; effluents and waste from industrial sources; the high demand for raw water collection for water supply systems (WSS); the capture of water directly from the basin's water courses for irrigated rice cultivation and the dependence on the transfer of water from the Caí River basin to the RSB (Sema, 2017; Silva, 2020).

Currently, the greatest environmental impact in the RSB is due to the high loads of untreated or poorly treated sewage. This is evident at the mouth of the João Correa Stream near the Sinos River, in the municipality of São Leopoldo (Figure 3). Across the BHRS municipalities, it is estimated that effective sewage treatment (advanced treatment plants) covers only 5% of the BHRS's domestic sewage load (Bassan; Silva, 2019). Financial resources earmarked for effluent treatment account for over 90% of the estimated amounts for the basin's environmental recovery (Comitesinos; Profill, 2014c).

Figure 3: Mouth of the João Correia Stream next to the Sinos River – Low Sinos – Domestic sewage being carried by the stream to the river – São Leopoldo/RS

Source: Ministério Público do Rio Grande do Sul (MPRS, 2010).

According to data available in the National Sanitation Information System (SNIS), in the reference year 2022, RS had a total sewage network coverage rate of 36% (Ministério das Cidades – MCidades, 2024, p. 72). However, it is important to note that the data available in the SNIS indicate the low coverage and precariousness of sanitation services in RS, including the municipalities of the BHRS, according to the data from the municipalities that report it. Equally significant is the fact that most municipalities in RS, and in the BHRS, declared that they did not have a public sewage treatment system or simply did not report their actual sewage treatment situation (MCidades, 2024, p. 63; SPGG, 2024d).

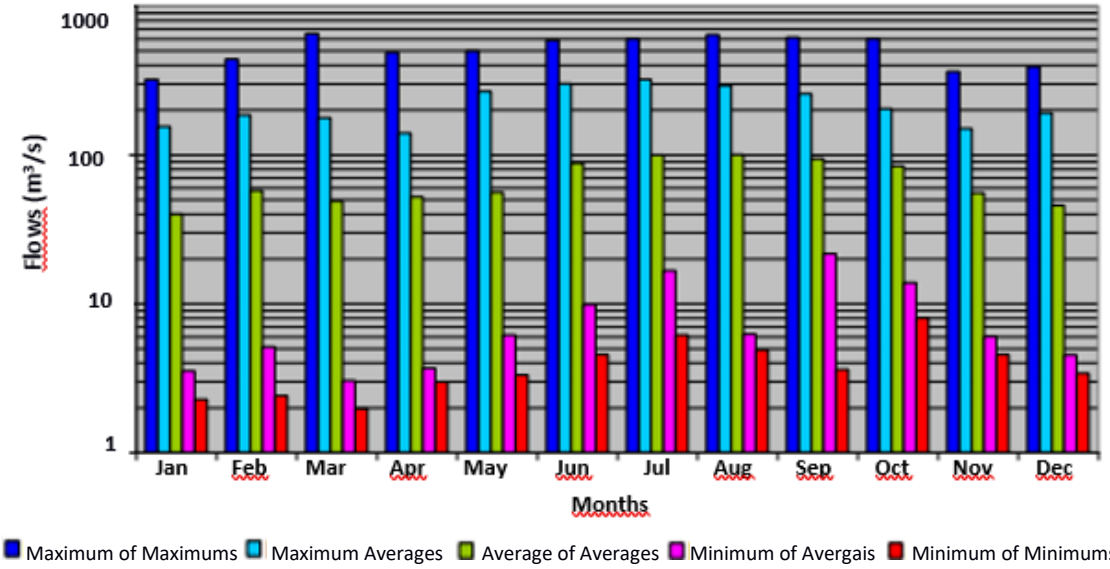
The National Sanitation Plan (Plansab) itself considers adequate treatment when sewage is collected, followed by treatment in sewage treatment plants (STPs), or when septic tanks are used (Ministério do Desenvolvimento Regional – MDR, 2020). There is a significant difference between these two situations. Technically, septic tank treatment is far from effective in sewage treatment plants (STPs) (Bassan; Silva, 2019). Furthermore, there is a lack of effective data on the regular maintenance of septic tanks and the proper disposal of generated effluents in appropriate collection networks or rainwater collection networks. Plansab, however, considers service precarious, and therefore deficient, when sewage is collected without treatment and when rudimentary septic tanks are used. And all other situations that do not fit into those mentioned above (adequate or precarious service) are classified as without service (MDR, 2020). These situations are those in which sewage is released directly into the storm drains, drainage ditches, water courses and springs (Marcon; Wesz Junior, 2024).

From the research perspective, the percentage of effective sewage treatment in STPs is considered, without considering the supposed treatments through simple

septic tanks or septic tanks and sumps (Bassan; Silva, 2019; Marcon; Wesz Junior, 2024). Evidently, these are present in the BHRS territory, but their effectiveness is practically null in terms of reducing the pollutant load discharged into the basin (as exemplified in Figure 3).

It is important to note that water contamination in a basin affects both the quality and quantity of water in the watercourse (Castro; A. L. A.; et al., 2019). There is a direct relationship between the amount of pollutant load and the quantity (flow rates) of water available in the watercourses. The role of pollution from sewage is clearly evident in the Sinos Basin Plan, which allocates more than 90% of the funds allocated to environmental recovery in the RSB specifically to treating this type of pollution load (Bassan; Silva, 2019; Comitesinos; Profill, 2014c; Pró-Sinos, 2014; Silva, 2020). In addition to the volume of sewage discharged into all of the basin's water bodies, the basin presents a variability in flow rates (Figure 4), which determines the weight of domestic sewage load in contaminating its waters. Given the recurrence of very low flows in Sinos, not only in summers, which reduce the dilution capacity of high domestic sewage loads (Agra, 2022).

Figure 4: Characteristic monthly flows of the Sinos River, in Campo Bom – Middle Sinos



Source: Agra, 2022.

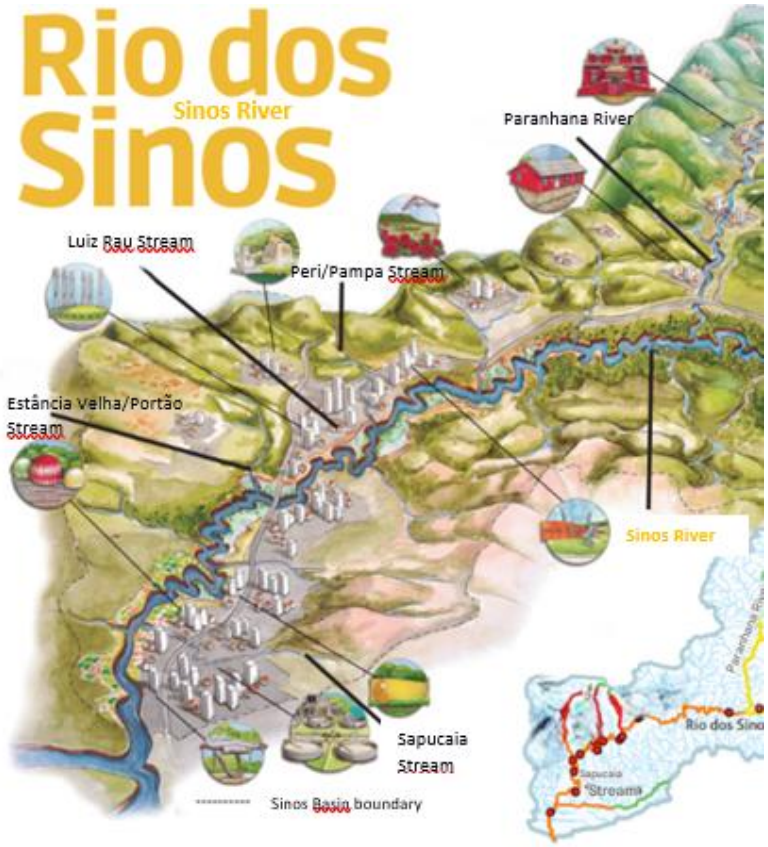
Figure 4, a graph of the characteristic monthly flows of the Sinos River in the municipality of Campo Bom, clearly demonstrates that flows are below 100 m³/s in all months of the year, even the wettest ones (Agra, 2022). This is evident when observing the columns corresponding to the "averages of the averages," which thus express the dynamics of the Sinos River's flows. The columns corresponding to the "minimums of the minimums" reveal the extremes of very low flows (below 10 m³/s), equally frequent in the Sinos River in all months of the year.

The pollution load resulting from intense industrial activity in the Lower Sinos region, as well as along the Paranhana River in the Middle Sinos section, has been of great significance recently due to its impact on the ecosystem. The Sinos River Valley

and the Paranhana River Valley currently have significant industrial presences, and both regions are within the BHRS (Figure 5).

There are records of industrial activity in the Sinos Valley dating back to 1890, in areas of São Leopoldo, municipalities from which others emerged, resulting in industrial economic activity (Silva, 2020). One of the industrial activities with a high environmental impact in the BHRS was tanning. Later, the sector grew with the footwear industry (Hinata *et al*., 2023; Schemes et al., 2013; Popp, 2021). The leather and footwear industry was concentrated in the municipalities of Novo Hamburgo, Campo Bom, Estância Velha, Portão, and Sapiranga (Nunes; Rocha; Figueiredo, 2019), but over time it expanded to other municipalities within the RSB, especially the municipalities of the Paranhana River, a tributary of the Sinos, such as Parobé, Taquara, Igrejinha, and Três Coroas. According to Popp (2021), pollution rates from industrial waste generated by tanneries were already "alarming" in the 1960s. The situation became absolutely critical in the 1980s, when the State Foundation for Environmental Protection – FEPAM, began to demand the treatment of effluents and the adequate disposal of leather waste (Martins, 2011; Naime; Fagundes, 2005).

Figure 5: Middle and Lower Sinos – Compartments most impacted by urbanization and industrialization processes



Source: Cut from Comitesinos; Profill, 2014b, p. 10.

One of the highly critical points for the RSB is precisely one of the tributaries of the Sinos River, the Portão Stream (which gave its name to the city of Portão and also runs through the municipality of Estância Velha), in the Low Sinos, whose mouth

is located in the Sinos River, near the borders of the municipalities of Portão, São Leopoldo, and Sapucaia do Sul. Reports of fish die-offs due to industrial contamination predate the great tragedy that occurred between October 7th and 9th, 2006 (Peixoto, 2021), when 90 tons of fish reportedly died in the Sinos River (Figure 6). These reports were already reported as recurring events both in the Portão Stream and in the Sinos River itself, in its course downstream of Novo Hamburgo (Naime; Fagundes, 2005).

Figure 6: More than a million fish died, was the news in Jornal VS on 10/09/2006

More than a million fish died in the environmental tragedy. Next to it, the cover of the VS newspaper from the time.

Source: Peixoto, 2021.

Since Normann *et al.* (2002), who demonstrated the presence of heavy metals in fish tissues from the Rio dos Sinos, there has been very little data on the irregular disposal of urban solid waste (MSW) and other contaminants, such as agricultural pesticides and animal waste, and their impacts on the RSB (Oliveira; L.A; Henkes, 2013; Wilbert; Quevedo; Pereira, 2018; Caetano; et al., 2024). However, evidence from daily empirical observations in streams and rivers of the RSB, during droughts and after floods, shows that this is a significant environmental problem, given its effects on water collection and treatment, and even on the natural conditions of the watercourses that make up the RSB and its ecosystems (Coan, 2024; Comusa, 2021; Faleiro, 2023).

More recently, after the great flood of April-May 2024, a study carried out jointly by the Technological Institute of Paleoceanography and Climate Change and the Technological Institute of Food for Health at the University of Vale do Rio dos Sinos provided unequivocal data on the contamination of the water and soil of the BHRS (Caetano; *et al.*, 2024).

A study by Caetano *et al.* (2024) found elevated mercury levels in sludge samples collected from the Vicentina and Scharlau neighborhoods of São Leopoldo.

Nickel contamination above the recommended levels was confirmed at six of the 13 sample collection sites. Four sites were found with chromium contamination above the recommended levels, two sites with copper contamination, and one site with cadmium contamination above the recommended levels. This study also identified excessive amounts of Escherichia coli, aerobic mesophilic bacteria, and total coliforms in all sediment samples collected (Caetano *et al.*, 2024).

It is also known that many environmental liabilities are deposited in the soil, often near the banks of the Sinos tributaries and rivers, especially the Paranhana and Sinos. These are former landfilled "dumps," and in some cases, they house highly contaminated waste resulting from decades of industrial processes in tanneries and the footwear industry. These liabilities are identified in municipal plans and the regional integrated solid waste management plan led by the Pró-Sinos Consortium (Pró-Sinos; Key Associados, 2012). This is the case with the former Taquara/RS landfill, in the Middle Sinos region (Figure 7). In addition to industrial waste, the former landfill also received, from 1962 to 2008, solid waste not only of industrial origin, but also of an organic nature and construction waste (Pró-Sinos; Servmar, 2012; Taquara; UCS, 2024).

Figure 7: Old Taquara landfill

Source: Pró-Sinos; Servmar, 2012 (Part A, p. 61).

In Figure 7, it is clear that both the landfill and the Empresa neighborhood are located along the right bank of the Sinos River, in its floodplain. Both cells are 50 to 100 meters from the right bank of the Sinos River and are upstream of the water company Corsan's water intake (Pró-Sinos; Servmar, 2012; Taquara; UCS, 2024). This makes the area of the former landfill and the Empresa neighborhood frequently hit by floods, such as those recorded in November 2023 (Taquara, 2023), the April-May 2024 flood (Jornal do Comércio, 2024), and the recent June 2025 flood (Taquara, 2025).

Given the soil characteristics, typical of the floodplains of the Sinos River, this area of the former Taquara landfill allows rainwater infiltration. This percolates over the waste layer, flowing into the capillary zone between the clay soil, infiltrating and carrying the leachate with contaminants, including heavy metals, until it flows into the river itself, as demonstrated by the study conducted by Pró-Sinos and Servmar (2012). The overall configuration of this important area, located in the Médio Sinos compartment, reveals a complex set of water insecurity, combining anthropogenic and natural factors, particularly the risks to water abstraction for human consumption.

The high demand for water withdrawal for human consumption, which impacts not only quantity (water availability), but also quality (Castro; A. L. A.; *et al*., 2019). Large sewage loads, in the face of a smaller amount of water in watercourses, result in less dilution of pollutant loads, among other consequences for the ecosystem, sewage treatment systems, and water withdrawal (Figure 8).

In the RSB, water supply systems (WSS) are operated by several companies, the main ones being: the state-owned company, Corsan (currently Corsan AEGEA), which operates in most municipalities in the RSB; Semae (an autarchy of the municipality of São Leopoldo); and Comusa (the municipal company of Novo Hamburgo). In some municipalities, there are incipient supply systems, with minimal collection structures through artesian wells. Overall, however, water supply is virtually universal in the RSB.

Figure 8: Aerial view of the Semae water intake along the Rio dos Sinos, upstream from the city center of São Leopoldo

Source: Semae (2017). Image Credits: Digue Cardoso.

The update of the RSB water balance, carried out by the Granting and Inspection Division of the Department of Water Resources and Sanitation (DRHS) (Sema, 2017), highlighted the overloading of the RSB ecosystem. This overload is due

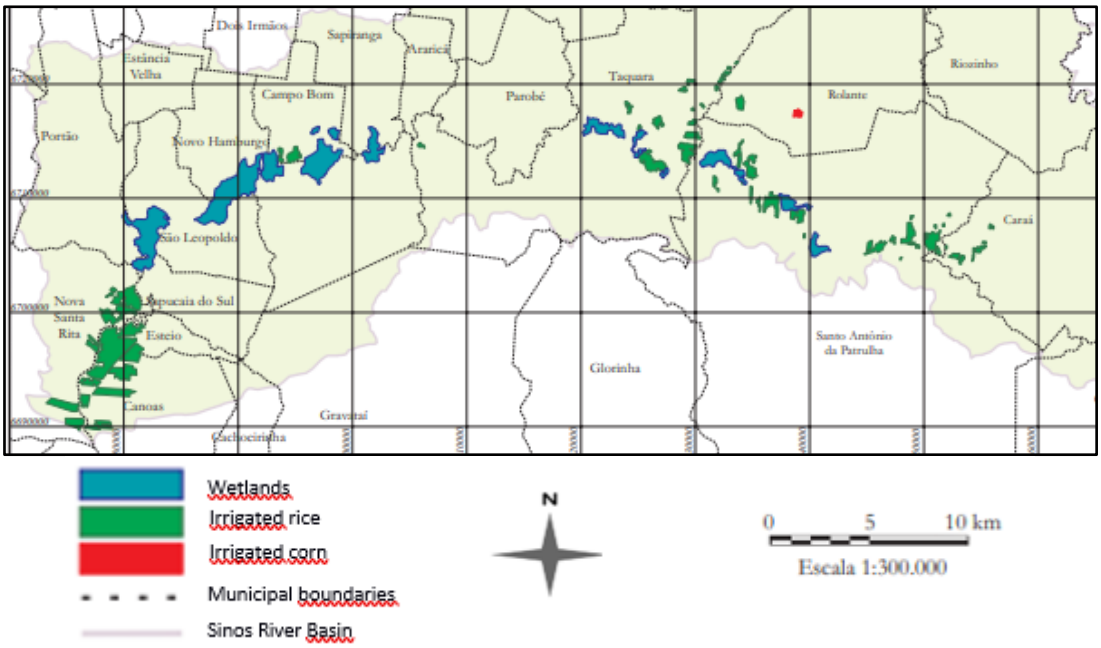
to the high water demand, in which the water supply segment for human consumption competes with other uses, especially rice crops. The data from this study are corroborated by technical note No. 002/2024/DIPLA/DRHS, from the DRHS's Water Resources Planning and Management Division (Sema, 2024). The data demonstrate the impairment of the grantable flow by up to 100% or higher in large segments of the RSB in the Upper and Lower Sinos compartments (Sema, 2024).

According to data from the Sinos Basin Plan (Comitesinos; Profill, 2014c), the share of consumption for human consumption in the RSB rose from 29.4 to 34.3%, comparing available data that express the context from the beginning of the basin plan studies until its publication in 2014 (Pró-Sinos, 2014; Comitesinos; Profill, 2014c). And, according to the water balance (Sema, 2017), a study conducted by the rice producers themselves demonstrated the existence of a water deficit in the AS8 (Upper Sinos) and Lower Sinos sub-basins. This compartment, in fact, presents itself as a major consumer of water for human consumption in the basin, precisely because it concentrates the largest cities in the RSB in terms of population (Sema, 2017, p. 29). Water demand occurs spatially, 76% in the lower portion of the Basin and 18% in the upper portion. This is precisely in the compartment with the highest population and industrial concentration, and where rice farming is also present, in the Low Sinos (Comitesinos; Profill, 2014c).

According to Technical Note No. 002/2024/DIPLA/DRHS (Sema, 2024, p. 2), the compromised grantable flow is 164% in the middle stretch of Upper Sinos and 148.4% in Arroio Caraá, located in Alto Sinos. These stretches have a sparse population. Considering that these segments of the basin are home to the municipalities of Caraá and Santo Antônio da Patrulha, Caraá has an estimated population of 7,553 inhabitants, and Santo Antônio da Patrulha has 44,393 (IBGE, 2024), this highlights the weight of the demand for water from agricultural use, to supply the rice crops present in the Upper Sinos territory.

Water collection for rice cultivation is present in the three sections of the RSB (Upper, Middle and Lower Sinos), along the Sinos River and its wetlands (wetlands), as can be seen in Figure 9, below:

Figure 9: BHRS section – Location of irrigated crops – Summer 2003/2004 – Wetlands and irrigated crops



Source: Adapted by the authors from Sigmap (2004, p. 13).

Irrigation for agricultural crops, and in this case, irrigated rice cultivation (Figure 10), has significant impacts on both the ecosystem itself (the entire RSB) and the systems dependent on the water from the basin's watercourses. It should always be noted that water availability (the quantity of water) is directly related to the quality of water for various uses (Castro; A. L. A.; et al., 2019; Castro, C. N., 2022). According to the Sinos Basin Plan, agriculture accounts for 47.10% of the RSB's total water consumption (Comitesinos; Profill, 2014c).

Technical studies, including the data contained in the preliminary version of the Sinos Plan (Pró-Sinos, 2014), showed an even higher percentage of water consumption for agriculture, at 57.7%. This reduction in the rice sector's share of water consumption is mentioned in the final version of the Sinos Basin Plan (Comitesinos; Profill, 2014c) and is believed to have occurred due to investments by the rice sector in technologies aimed at rational water use in irrigation and improved productivity gains. The replacement of rice areas with other, more profitable crops that require smaller volumes of water also contributed to this decrease.

With this reduction in water consumption for rice farming, the percentage shares of other sectors increased, especially human supply, which rose from 29.4 to 34.3%, and industry, from 10.9% to 16.6% (Comitesinos; Profill, 2014c).

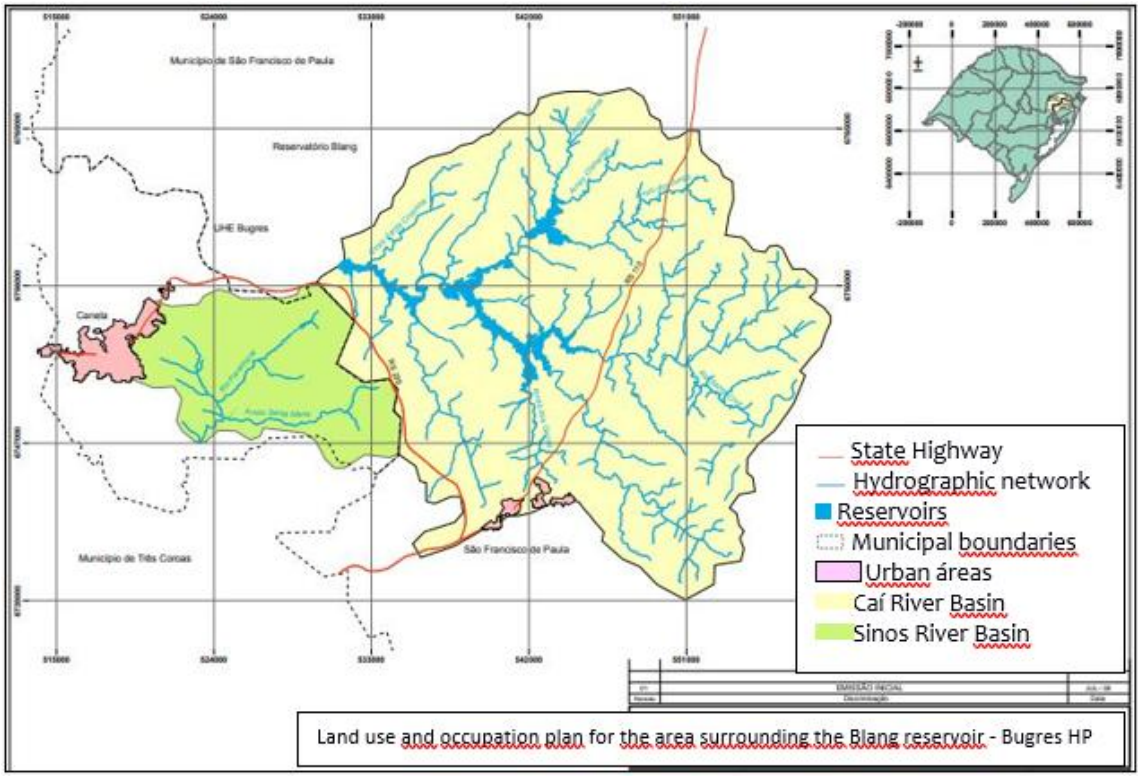
Figure 10: Rice cultivation in the floodplain – Upper Sinos – Landscape of the Sinos River – View from the plain to the mountains

Source: Anschau, 2016, p. 13. Image Credits: Guto Maahs.

The final version of the Sinos Basin Plan (Comitesinos; Profill, 2014c) downplays the impact of rice cultivation on the RSB. However, although technological advances have reduced rice's share of water capture and consumption in the RBS, this crop remains a major water consumer. It continues to compete primarily with water supply for human consumption. Regarding water security and water governance in the BHRS, rice cultivation remains a significant factor in the basin, given the region's climate variability, the irregular flow of the Sinos River, and the population, particularly in the Lower Sinos. These factors, combined with increasingly frequent droughts (Santos, M.A., 2022; SPGG, 2024b), generate water insecurity for the human population and for the ecological sustainability of the region's ecosystems.

Another determining factor for water security in the RSB, mentioned in the Basin Plan (Comitesinos; Profill, 2014c), is the dependence on water transfer from another basin, the Caí River (RCB). The Salto System in the RCB has three dams located in the Upper Caí, the upper reaches of the basin (Figure 11). This system regulates flow for electricity generation in the RSB. This water transfer process between the two basins occurs through the Salto-Bugres tunnel (Figure 12), which allows water to flow into the Santa Maria River, and from there into the Paranhana River, which in turn flows into the Sinos River, in the municipality of Taquara, in the Middle Sinos section (Ceee-gt; Profill, 2011).

Figure 11: Location of the Salto System

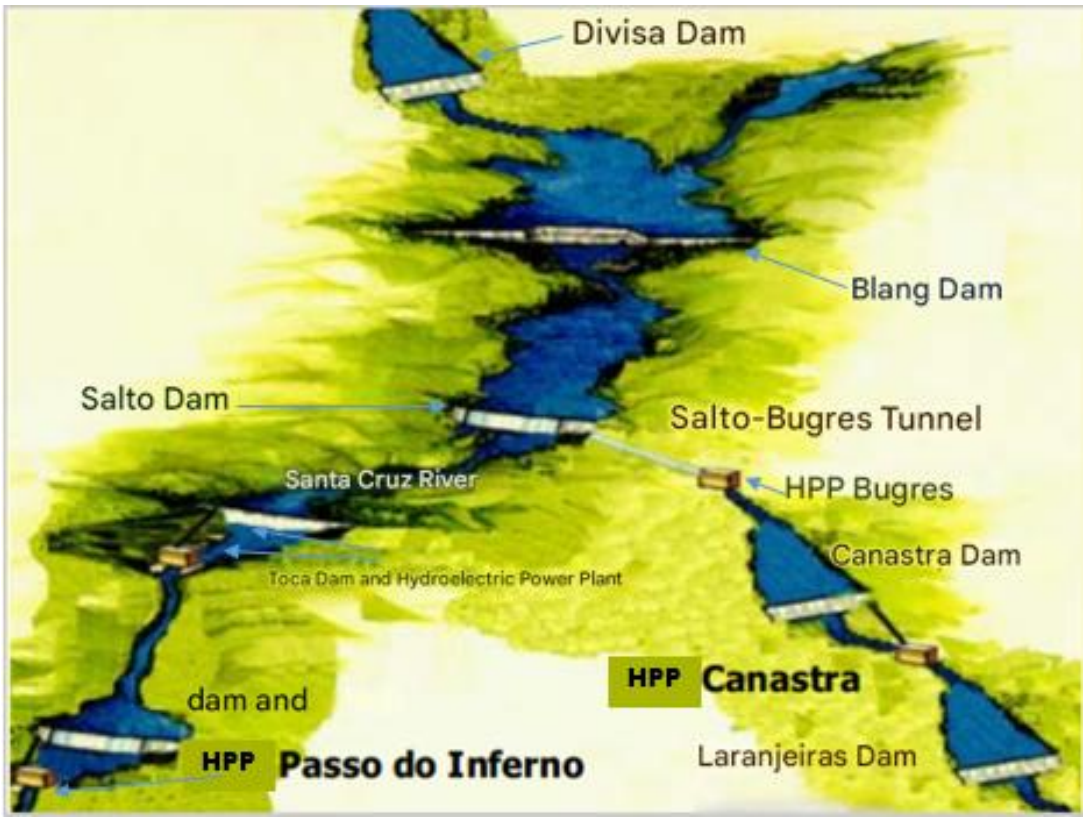


Source: Ceee-gt; Profill, 2011, p. 4.

The dependence on water diverted from the RCB (Brazilian Water Resources Regulatory Board) marks a point of great vulnerability for the RSB (Brazilian Water Resources Regulatory Board) in terms of water security, requiring further study. Currently, it would be necessary to increase the volume of water diverted from the RCB to the RSB to balance availability and demand conditions in the Lower Sinos. This is inferred from data contained in the Sinos Basin Plan (Comitesinos; Profill, 2014c); the technical study by the Water Resources Granting and Oversight Division of SEMA RS (Sema, 2017); and technical note No. 002/2024 from DIPLA/DRHS (Sema, 2024).

There has been population growth throughout the RSB's recent history, especially in the last decades of the 20th century, when this population increase occurred parallel to the expansion of industrial activities and rice cultivation in the RSB (Silva, 2020). Planning to accommodate this expansion considered the need to increase electricity generation capacity. The implementation of this diversion system (Figure 12) to generate energy in the late 1950s and mid-1960s was fundamental to increasing the amount of water available in the Sinos River from the mouth of the Paranhana River, near Sinos (Ceee-gt; Profill, 2011).

Figure 12: Water transfer system from the Caí Basin to the RSB



Source: Adapted from Geraldi, 2013.

This volume of water transfer adds 25 to 40% of the RSB's water availability to the Sinos River. Even so, there is a water deficit in the Lower Sinos and a growing demand in the Middle Sinos, with several sectors in this stretch close to experiencing water deficits (Comitesinos; Profill, 2014c; Sema, 2017). Therefore, it can be deduced that if the volume of water transfer did not occur, the water supply for human use in the Lower Sinos River would certainly collapse. In this sense, human intervention, in the form of a water transfer and power generation system, has resulted in a change in the hydrological variability of the Sinos River. This system, therefore, contributes to the water quality of the Middle and Lower Sinos Rivers. Without it, the concentrations of pollutants in the water would be even higher (Comitesinos; Profill, 2014c; Sema, 2017; Castro; A. L. A.; et al., 2019; Castro, C. N., 2022).

In this regard, when water availability is low in the RSB, the diversion system contributes to water security. On the other hand, when there is an extreme volume of water in both the Caí and Sinos basins, as in the great flood of April-May 2024, the risk of ruptures in this system becomes a high-risk factor for water security (Figueiredo, 2024).

This is possibly the most obvious example of water insecurity in the RSB. Hours of interruption in the water transfer from the Caí to the Sinos River during a dry season could already mean the collapse of the water collection and supply systems for the majority of the RSB population. At least two recent events have highlighted the risks to water security associated with the water transfer operation from the RCB to the RSB.

From the research findings, it is clear that urban expansion and industrialization, especially in the second half of the 20th century, resulted in significant damage to the RSB. However, this finding is not solely based on empirical observations, or even the memory of generations. Scientific studies provide highly relevant data regarding this environmental impact. Moura (2016) demonstrated that, as a result of the expansion of human occupation of the RSB "over the last 30 years," the basin lost 70% of its wetlands. His research correlates the impacts of this reduction in wetlands with the impacts on municipalities in the region, especially during periods of drought and flooding: "Last summer [referring, therefore, to the summer of 2014/2015], for example, Novo Hamburgo and São Leopoldo had significant difficulties in treating their water precisely because of the low river level and the lack of wetlands in the Basin. During periods of flooding, as occurred this year and last year, the opposite process occurs, with flooding in the cities" (Moura, 2016).

Urbanization in wetlands has been increasing since the 1980s, resulting in irreversible damage, as these areas cannot be restored. Thus, for the researcher and for Comitesinos itself, based on the provisions of both the Basin Plan (Comitesinos; Profill, 2017) and the study on floodplains (Comitesinos, 2016), the only remaining objective is to preserve the wetlands still existing in the RSB. The preservation of forests, vegetation (including fields), and wetlands depends on the preservation of 359 tree species, 353 bird species, and 110 fish species cataloged in the RSB (Comitesinos, 2016).

4 Results and discussion

As evidenced, the urbanization process of the RSB territory, particularly the rapid urbanization from the 1970s to the end of the 20th century, significantly exacerbated anthropogenic impacts on this ecosystem. This compromised its environmental sustainability and water security. Environmental sustainability is compromised in this historical context, as the ecosystem's water demands reached their limit precisely in this context, due to notable water stress. And, as a consequence of this abuse of the RSB "natural system," the risk of a scenario of growing water insecurity has risen to the current governance agenda. The current reality of the RSB is one of recurring and growing water insecurity because:

a) There has been a drastic reduction in its wetlands and forest cover in both the Atlantic Forest and Pampa biomes, compromising springs and wetlands, environmentally essential to the water security of the RSB (Anschau, 2016; Moura, 2016);
b) Population, industrial, and agricultural growth, with their attendant water consumption, has led to frequent water stress in the RSB ecosystem, both during the most characteristic periods of the climatic seasons, such as spring and summer, and during periods of drought. This has led to permanent water deficits in the Lower Sinos River and frequent episodes of risk to water collection, treatment, and availability for domestic, industrial, and agricultural uses (Comitesinos; Profill, 2014c; Sema, 2017);
c) Consequently, recurring water stress and periods of water scarcity (Castro; A. L. A.; *et al*., 2019) in the BHRS worsen both water quantity and quality conditions, worsening the effects of different pollutant loads; which

consequently requires even higher-cost systems and inputs to adapt water quality to consumption, considering that the water in the Sinos River is predominantly class 4 from the Middle Sinos section to the mouth near the Jacuí Delta (Comitesinos; Profill, 2014c; Hinata; et al., 2023);

d) This consumption, in turn, through constant water stress, also maintains stress on the various living systems that make up the RSB ecosystem (Anschau, 2016; Moura, 2016);

e) The existing dependence on the transfer of water from the Caí River Basin (RCB), which currently marks the point of greatest vulnerability of the RSB in terms of bater security [and requires further study]. Currently (2023/2024), it would be necessary to increase the volume of water transferred from the RCB to the RSB to balance availability and demand conditions in the Lower Sinos. These conditions are obviously deduced from the data contained in the Sinos Basin Plan (Comitesinos; Profill, 2014c), the technical study by the Water Resources Granting and Inspection Division of SEMA RS on the water deficit in the RSB (Sema, 2017), and technical note no. 002/2024/DIPLA/DRHS (Sema, 2024);

f) The territory of RS, and therefore that of BHRS, has a history of more than 100 documented years of recurrence of storms and cyclones, and the intensification of the alternation of extreme events: recurrence of large-scale floods, more prolonged droughts, extreme heat temperatures, rainfall with very irregular distribution across the territory, and the devastating cyclones recorded recently, in 2023, under the effects of a Super *El Niño* (Sias, 2024).

And, despite the debate about how much these phenomena result from natural variability and how much from human actions (Sias, 2022, 2023, 2024), it is important to note that these conditions are present in this space and likely result from the synergy between different natural and/or anthropogenic factors. However, it is known that the model that has been imposed on the RSB territory to date is structured on the basis of overexploitation of natural resources.

Currently, water insecurity caused by extreme events (Metsul, 2022; 2023a, 2023b, 2023c, 2023d; Oliveira, B., 2020; Santos, M. A., 2022), especially droughts, flash floods, floods, and cyclones occurring in several events at intervals much shorter than what was seen as a standard in the RSB, which would be ten years, has been a constant. Coincidentally, during the course of this research, there were, in the period from June 2023 to June 2024, 12 extreme hydrological climate events recorded in RS. Among these 12 events, in 6 of them, the RSB was directly and severely affected: 15 to 17/06/23, 16 to 19/10/23, 17 to 22/11/23, 17 and 18/01/24, 27/04 to 31/05/24, 22 and 23/06/24 (From the authors, 2025).

These events clearly sparked a renewed discussion about flood containment projects (Metroplan, 2018), including whether they are effective in extreme cases such as those that occurred in 2023 and 2024. This issue also includes financial, environmental, and social costs (Dos autores, 2025). This mobilized several entities, some with specific responsibilities in water resources, civil defense, and planning and governance. But most notably, it refocused the basin committees on water security within the basins. And, in the case of the RSB, it brought water governance and water security issues back onto the agenda of the current Comitesinos configuration. These

were precisely the discussions that were on the agenda when Comitesinos was created 37 years ago. The current agenda includes the discussion about basin committees having the conditions to effectively manage state river basins (Agra, 2022; Comitesinos, 2024).

The reality of the RSB reveals the existence of a governance deficit in Rio Grande do Sul, regarding water resources management. This governance deficit is reflected in the ineffectiveness of public policies in the area of water management. The governance deficit is connected to two other deficits: the basic sanitation deficit and the lack of water itself (water deficit). This constitutes a triple deficit that affects public water resource policies in Rio Grande do Sul. The severity of this reality is such that one can consider the hypothesis that it would not be enough for the RSB to advance to 100% treated sewage, which would still lead to water stress and, therefore, *water insecurity*, due to the risk of water shortages in most of the 21 RSB study units.

In addition to environmental recovery measures, especially those aimed at sewage treatment, which are present in the Sinos Basin Plan (Comitesinos; Profill, 2014c), the following are understood as necessary measures for water security in the RSB in light of the IRBM (Gleick, 2018; Hooper, 2005; Silva, 2020):

- The full implementation of an effective Integrated Water Resources Management System (IWRMS) in RS, with the creation of one or more river basin agencies (RBAs); elements present in the Rio Grande do Sul water law (Rio Grande do Sul, 1994), which referred to agencies by river basin region, seems to be adequate to the hydrographic structure of RS;
- The implementation of charging (pricing) for the use of raw water (water collected directly from water courses), as an instrument for inducing more effective technological processes in all existing water uses;
- Improvement and greater integration of existing instruments and bodies for water governance, environment, environmental sanitation and civil defense at the State Government level and with municipal bodies, existing intermunicipal organizations (example: Consórcio Pró-Sinos) and Comitesinos itself;
- Greater and better coordination between the instruments and bodies of the IWRMS and other structures of the State and civil society itself that perform functions related to the management of WR or basic sanitation in general (sanitation companies);
- Creation of an interfederative body, similar to interfederative consortia, for strategic governance, operational management and maintenance of the flood protection system in the Porto Alegre Metropolitan Region, which could, through the expansion of responsibilities, implement and operate future regional systems, where technical studies indicate the need to implement similar systems;
- Review of the water reservation and transfer system from RCB (Caí) to RSB (Sinos), with the possible expansion of the water reservation in Alto Caí and the increase in flow to Sinos, through the Paranhana River basin (Middle Sinos);
- And implementation of joint guidelines for urban expansion conditioned on the existence of highly efficient mechanisms for reserving and reusing water,

protecting and conserving springs and, equally, permanent preservation areas, ecological corridors and environmental parks in urban areas.

5 Final considerations

This article seeks to analyze water insecurity within the RSB from the perspective of integrated river basin management (IRBM). As seen, the RSB is an area where there has been an exponential increase in water demand and pollutant discharges, with significant increases beginning in the 1970s. This investigation has uncovered the water scarcity experienced in the RSB. This is a state of near-permanent insecurity in the basin, imposed by anthropogenic actions, climate variability, and the dynamics of hydrological flows throughout the basin.

Based on data available in technical studies and other documentary sources related to the RSB, it was also evident that there are synergistic effects of urbanization, industrialization, and climate change that challenge water resource governance in the region. In particular, as a clear analogy to the water deficit, there is a water governance deficit in RS, based on the case of the RSB, a state basin. This occurred 37 years after the creation of Comitesinos and 30 years after the enactment of the state law on water resource policy and system for the state of RS. This policy has not yet been fully implemented, given the lack of even a basin agency and the lack of charges for water abstraction from the rivers in the state. These instruments are indispensable to the effectiveness of the water management system.

It is understood that the study presented here can contribute not only to a better understanding of the current state of the RSB, but also to the improvement of its conditions through the effective implementation of the management instruments provided for in the legal and institutional system and tested in similar conditions with proven effectiveness.

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