



Water reuse in industries: analysis of opportunities in the Paraíba do Sul river basin, a case study in Presidente Vargas Plant, Brazil

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Abstract

In recent years, the demand for clean water has been growing all over the world despite the different threats posed, including increasing pollution, increasing deforestation and climate change. Industrial activity is the second largest consumer of water, so highly industrialized regions are more susceptible to water stress. In this sense, reuse strategies have been progressively discussed and used around the world; however, in Brazil there is still place for many advances, whether due to lack of incentives, cultural issues in society, or poor regulation of the subject. The objective of this work was to carry out a diagnosis of raw water uptake by industries in one Hydrographic Region of the state of Rio de Janeiro and to propose a discussion on the adoption of water reuse practices for non-potable purposes from the use of treated effluents. A survey of the theoretical framework on the subject was carried out, as well as an analysis of sustainability indicators and reports of the companies, including the current licensing processes of large undertakings consuming water resources. With this study, it was possible to obtain the average cost of implementing a water reuse unit for an industry in the state of Rio de Janeiro-Brazil, which, despite still being expensive, has a strong tendency to use due to world water shortages. Finally, it was concluded that the state of Rio de Janeiro has a threat of water scarcity that could be aggravated in the coming years, if measures and investments in supply alternatives are not adopted (water reuse), and improvement in all stages of water management water resources.

Keywords Water resources · Wastewater treatment · Environmental licensing

Introduction

Several parts of the world are already facing problems related to water scarcity, and there are predictions that this will be one of the most sensitive environmental issues in

the coming decades, in line with population growth, the unequal distribution of resources, increasing pollution, and climate change (Valipour 2015; Pintilie et al. 2016; Gosling and Arnell 2016). Despite the crises related to water insufficiency in many countries, the poor management of this resource contributes to the scarcity scenario in places where, in the past, it was believed that there was plenty. Faced with this scenario, the commitment and participation of governments, civil society, and the private sector in defining responsibilities and taking actions for the proper management of water resources are increasingly necessary (Zhang et al. 2021). Environmental issues related to water resources range from preservation and management, even their excessive consumption linked to civil construction activities, such as water consumption in the production of concrete and masonry, which generate enormous environmental damage (Fan et al. 2023; Nunes et al. 2024).

Access to clean water and sanitation was recognized as a human right by the United Nations General Assembly in 2010, and it is a fundamental resource for human health,

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food production, social and economic development and maintenance of biodiversity (Trevett et al. 2005; Tundisi and Tundisi 2015; Young et al. 2015; Brown et al. 2016; Pereira Ribeiro et al. 2021). With the increase urbanization and population, greater pressure on water resources and a greater generation of domestic effluents are expected, which leads to a great potential for this type of reuse (Drechsel et al. 2015; Zhao et al. 2019; Qadir et al. 2020). In recent decades, advances in treatment levels are notorious, allowing the reuse of wastewater for different purposes (Lyu et al. 2016). Unfortunately, the portion of wastewater produced worldwide that effectively undergoes treatment and is reused is still small (Jin et al. 2023).

The importance of dealing with this issue is also expressed in one of the seventeen goals of sustainable development, elaborated by the United Nations, which address the main challenges of the economic, social and environmental dimensions faced by humanity (Guimarães and Ferreira 2020). Among the objectives stands out the SDG-6, which aims to ensure the availability of water, its sustainable management and sanitation for all (Masi et al. 2018). According to Sena et al. (2016), increasing the recycling and safe reuse of water is one of the pillars for achieving the commitments made, as stated in goal 6.a.

Among the established reuse criteria, some uses are questioned, especially when it comes to reuse for human consumption or agricultural production, with reuse in industrial processes being the most accepted by public opinion (Voulvoulis 2018). It is increasingly necessary that reuse is seen not as an isolated practice, but as one of the constituent pillars of the emerging circular economy, which replaces the concept of linear economy based on reduction and, alternatively, reuse and/or recycling of resources in the production, distribution and consumption processes, seeking to minimize the extraction of natural resources combined with economic development (Kirchherr et al. 2018; Petit-Boix and Leipold 2018; Voulvoulis 2018).

Freshwater distribution and reuse in Brazil

Although Brazil is in a privileged position and is one of the countries with the largest distribution of fresh water in the world, the geographical distribution in the territory is quite irregular (Cirilo 2015). In addition to problems related to the distribution of water resources, there are events associated with loss in distribution systems, pollution and inadequate management of this resource (Santos et al. 2016; Kolbel et al. 2018). Currently, there are still challenges related to the severe water crisis observed in some river basins with values below historical averages (Getirana et al. 2021) added to the health crisis, due to the Coronavirus pandemic, which increased pressure on resources mainly due to the growing

need to wash hands and sanitize environments (Sivakumar 2020; Donde et al. 2021).

Effluent treatment technologies and methods for a diagnosis analysis of reused water

Effluents are characterized by the presence of organic and/or inorganic matter, such as microorganisms, heavy metals, oils and greases, and may also have unwanted characteristics such as acidity, alkalinity, turbidity, toxicity, color, and odor (Batista et al. 2020). In this way, the treatment of effluents seeks the efficient removal of the pollutants contained therein, based on normative parameters, and varying according to the volume to be treated, the purpose, the original characteristics and the place of release or possibility of reuse (Colla et al. 2016). Such treatment systems remove contaminants from unit operations and processes that can be classified according to the type of process used (physical, chemical or biological) and the degree and efficiency of pollutant removal, being called: preliminary, primary treatment, secondary, and tertiary treatment (Machineni, 2019; Sanz et al., 2015).

In recent decades, advances in treatment levels are notorious, allowing the reuse of wastewater for different purposes (Lyu et al. 2016). According to Pintilie (2016), the conventional treatment of municipal effluent treatment plants does not eliminate some water pollutants, such as: pharmaceutical products, drugs, hormones, pesticides, additives, food, among others, with advanced treatment processes (tertiary) mainly aimed at removing these pollutants. Tertiary treatment can include membrane bioreactors, nanofiltration, reverse osmosis, among others (Chon et al. 2011; Han et al. 2016).

The reuse water analysis and diagnosis process go through different stages and indicators, which have already been discussed in some previous research. The first refers to the collection and sampling stage to identify the main constituents and potability indicators of this water, serving as an important tool for determining which treatment method is most effective (Ghafoori et al. 2022). Thus, with the collection and sampling, analytical reports can be issued based on the collection of small samples in suitable and properly sanitized bottles with controlled temperature, avoiding changes in the results (Demerdash et al. 2022). The collection of samples and their packaging is one of the most important steps in monitoring the quality and reliability of the results, depending on its correct execution, and must be performed by certified professionals (Vaghasiya et al. 2022).

In the laboratory, one of the most common methods is the determination of the contents of constituents in the collected sample and their comparison with normative standards, which serve as a diagnostic method for the report (Bonetta et al. 2022). There are different methods of analysis

described in the literature, such as physical processes linked to the separation and quantification of constituents, such as spectrometry, spectroscopy, turbidimetry and others, chemical processes that use chemical transformations as the primary basis for separation and quantification, highlighting volumetry, titration, combustion, gravimetry, and others, and also processes through gas and liquid chromatography, which are separation techniques that make use of physical and chemical methods for quantification and detection (Fan et al. 2023). There are also electrochemical methods that are based on measurements of voltage or current flows associated with chemical transformations, such as conductometry and potentiometry (Batista et al. 2020). The wide variety of diagnostic analysis methods makes the literature provide a large possible framework, but still often expensive and difficult to implement. With the results, it is possible to effectively compare the values found with national and international standards of analysis, such as Standard Methods for the Examination of Water and Wastewater, American Public Health Association (APHA), American Water Works Association (AWWA), Water Environment Federation (WEF), Environmental Protection Agency, Environmental Company

of the State of São Paulo and Brazilian Association of Technical Norms (ABNT) (Voulvoulis 2018). The evaluation of chemical and physical parameters of quality is important to understand the functioning of ecosystems and environmental problems, in addition to proposing viable solutions for water reuse and the methodologies used. Thus, the need to apply safe and accurate methodologies and be carried out by reliable laboratories is justified (Shamaki et al. 2021).

Rio de Janeiro (Brazil) study reuse scenarios

According to the 2014 State Plan for Water Resources of Rio de Janeiro-PERHI-RJ, the greatest demands for water in the state of Rio de Janeiro are for human supply and industrial use. The industrial sector's demand for water is predominant in Hydrographic Regions II (Guandu), III (Middle Paraíba do Sul) and IX (Lower Paraíba do Sul and Itabapoana), Fig. 1 (INEA, 2014; Romano, 2020).

In the horizon of 2030, for all the scenarios studied in PERHI-RJ, the demand of the industrial sector for water resources tends to have a considerable increase, and points to the opportunity to implement reuse strategies for

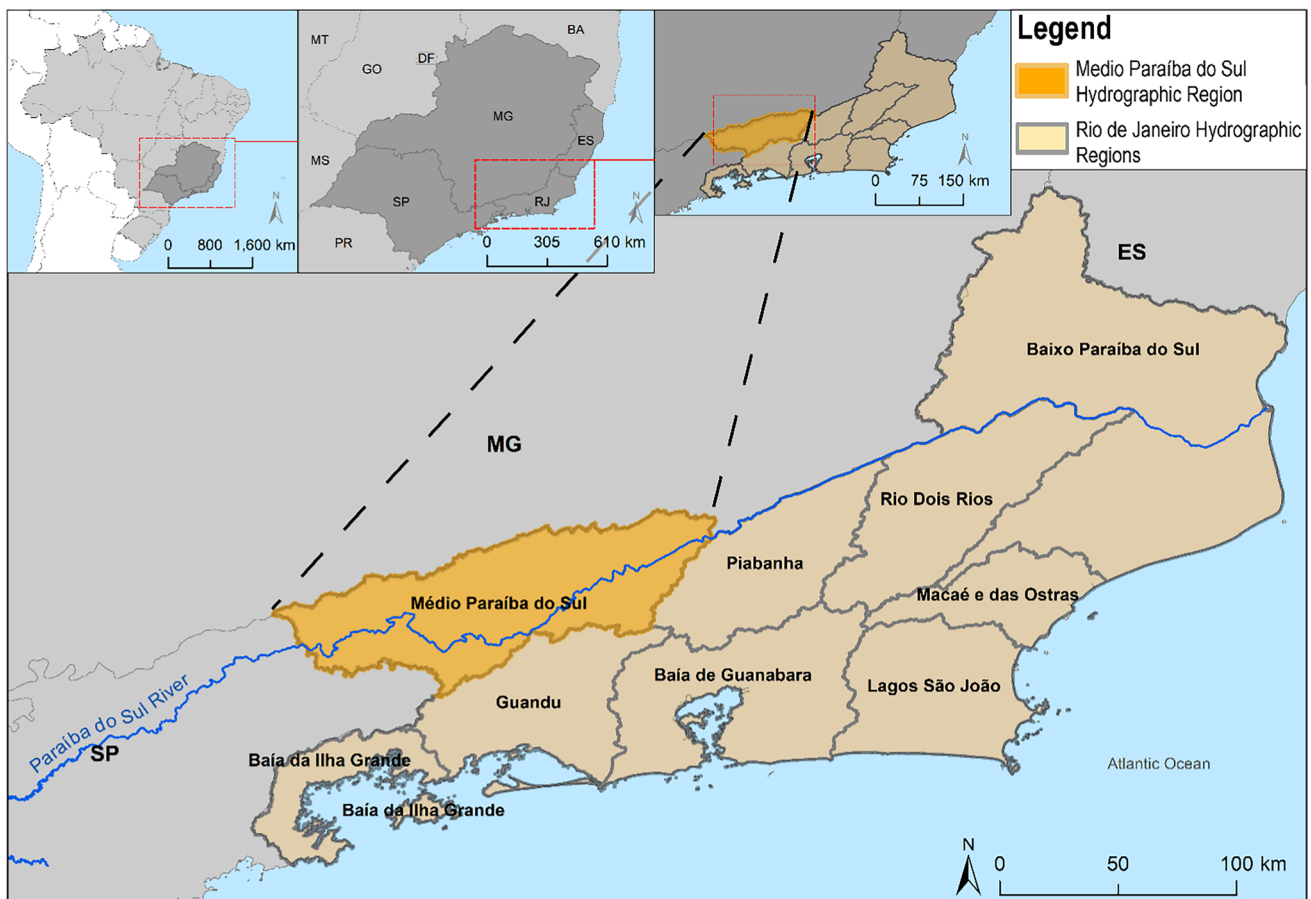


Fig. 1 Hydrographic Regions of the State of Rio de Janeiro

supplying this sector (INEA, 2014). In 2019, Industry Federation of the State of Rio de Janeiro (FIRJAN), together with the National Industry Confederation (CNI), released a Technical Note aiming to present a set of Effluent Treatment Stations with feasibility for supplying reused water in the state of Rio de Janeiro, in order to increase water security and reduce pressure about the springs that supply the population.

In legal terms, the Federal Law no. 14.026/2020 (Brasil, 2020) provides for the establishment of universalization targets so that by 2033, 99% of the Brazilian population will have access to potable water and 90% to sewage collection and treatment, and Article 6 of the State Law no 9.043/2020 which provides conditions for large polluting industries to use water reuse techniques within their industrial processes to request environmental licenses (RIO DE JANEIRO, 2020).

Although there is still a long way to improve the regulation of the theme and definition of parameters for reuse, there's a movement toward the elaboration and institutionalization of practices.

In the State of Rio de Janeiro, the environmental licensing processes are governed by Decree no. 46.890/2019, through this legislation the State Licensing System and other control procedures are established, which provides, among others, for the issuance of previous licenses, installation, operation and water use permits (Rio de Janeiro, 2019). For the successful implementation of reuse projects, it is extremely important that the government, together with other sectors of society, build technical standards that support the application of the proposed laws so that they are incorporated in the Terms of Reference for new projects, execution of Conduct Adjustment Agreement (TAC) or inclusion of license conditions that provide for the mandatory use of treated effluents for industrial use.

This work has as general objective to analyze the current situation of raw water abstraction by industries from the state of Rio de Janeiro (Brazil) located in Hydrographic Region III — Médio Paraíba do Sul, where the accentuated conflicts of multiple uses (domestic and agricultural consumption) of water and the diversion of water to other hydrographic basin, indicate the need to adopting water reuse practices for non-potable purposes from the use of treated effluents for industry. It should be noted that there is a huge deficiency in current studies on water reuse in areas of high consumption in Brazil, which has large reserves of fresh water in the world, and that these researches can help to promote public policies so that other countries encourage the water reuse. To achieve this objective, this work proposes an exploratory research based on the literature on the subject, in addition to defining a case study of companies that consume large amounts of water, enabling the quantification of costs for the implementation of water reuse units.

Materials and methods

From the identification of the problem and formulation of the objectives, an extensive search was started in the database of the Journal Portal of the Coordination for the Improvement of Higher Education Personnel (CAPES), through access through the platform of the Federated Academic Community (CAFe), and consultations in Federal Government databases, in bodies such as the Brazilian Institute of Geography (IBGE), National Sanitation Information System (SNIS), National Water and Sanitation Agency (ANA), State Government database of Rio de Janeiro, as the State Environmental Institute (INEA) reports from the Middle Paraíba do Sul Committee, and sustainability reports.

Step 1: Definition of the study area

The Paraíba do Sul river that runs through three Brazilian states, São Paulo, Minas Gerais, and Rio de Janeiro, has a social and economic importance, being located in one of the most industrialized regions of the country, in addition to its use in agriculture and for supplying the population (Cavalcanti and Marques 2016; Miguens et al. 2016; Paiva et al. 2020). The Paraíba do Sul basin covers 184 municipalities, 39 in São Paulo, 57 in Rio de Janeiro, and 88 in Minas Gerais, and has, according to the IBGE (2021), a population of approximately 6.7 million inhabitants, according to Fig. 2 (Cavalcanti and Marques 2016).

Hydrographic Region III, defined by Resolution no 107/2013 of the State Council for Water Resources of the State of Rio de Janeiro - CERHI/RJ, Fig. 2, comprises, in its entirety, the cities of: Itatiaia, Resende, Porto Real, Quatis, Barra Mansa, Volta Redonda, Pinheral, Valença, Rio das Flores, C. Levi Gasparian, and partially: Mendes, Rio Claro, Piraí, Barra do Piraí, Vassouras, Miguel Pereira, Paty do Alferes, Paraíba do Sul and Três Rios.

In addition to its vocation for meeting industrial demands, the Paraíba do Sul river is a system of enormous importance for the state of Rio, due to the water transfer system for the Guandu river, initially conceived for electricity generation, and today, main source of public supply in the Metropolitan Region of Rio de Janeiro, serving around 80% of the population of the metropolis or 9.4 million people, according to Britto et al. (2019). Besides that importance, the Cantareira System, which is responsible to serve part of the Metropolitan Region of São Paulo, can receive water from the Paraíba do Sul River basin, through a transposition carried out between the Jaguari (Paraíba do Sul River Basin) and the Atibanha (Cantareira System) dams, a fact that is ongoing during

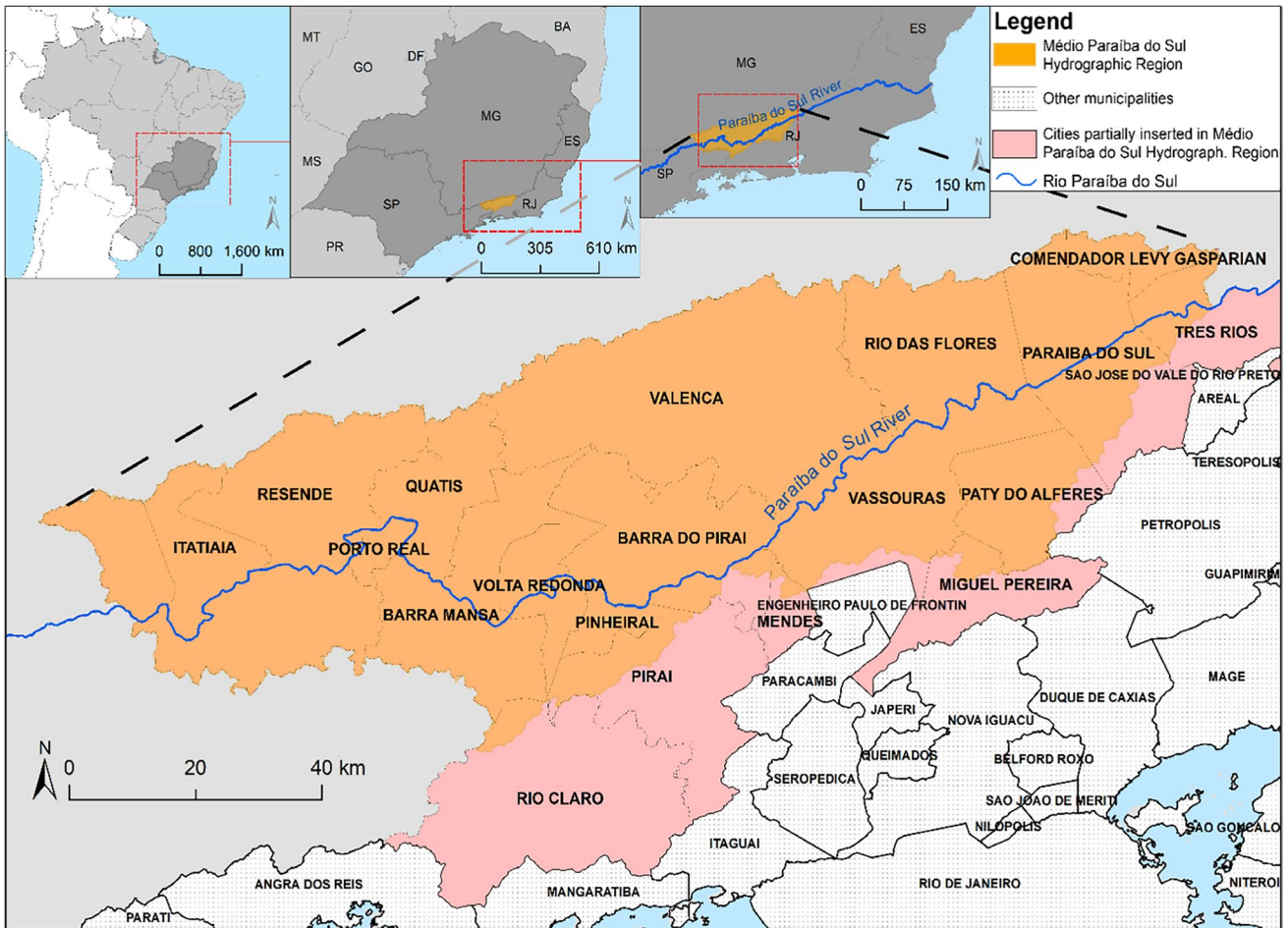


Fig. 2 Coverage area of the Médio Paraíba do Sul Hydrographic Region

2021, i.e., specific research in this area of study has an impact on the lives of more than 20 million people, which corresponds to almost 10% of the total population of Brazil (ANA, 2021; Billerberck and Junior, 2018; Cavalcanti and Marques, 2016).

Step 2: Survey of potential reuse water consumers

After defining the study area, a survey of the industries holding concessions for the capture of water resources in the region was proposed, based on consultations carried out in the ANA and INEA databases, water resources management bodies, as well as consultations with Users National Water Resources - CNARH, database that contains the records of users who collect water, release effluents or carry out other direct interference in water bodies (ANA, 2021; INEA, 2021).

Step 3: Survey of potential reuse water suppliers

With the definition of the largest users, a search was proposed in the strategies already performed, or not, by the users in their management of water resources and the survey of information on sanitation in the municipalities where they are located, as well as the location of Effluent Treatment Stations (ETE) in the vicinity of industrial areas. Based on criteria adopted by the National Confederation of Industry (CNI) to calculate the investment required for the implementation of reuse, reservoir and distribution plants, a comparison was made between the investment estimate and the amounts already paid by the industrial companies to capture raw water in the watershed in question.

Step 4: Calculation of economic feasibility

To calculate the cost estimate, the base developed by the CNI (2017) was used, which aimed to present possible scenarios of generic and viable infrastructure to be designed for the supply of non-potable reuse water for industrial purposes, estimating the Capex, characterized by the amount of resources invested in the acquisition or improvement of goods, and Opex, characterized by the amount of resources spent necessary for the organization to function (Lauría, 2013), associated with the respective average final costs, to guide the implementation of any reuse plants in Brazil (CNI, 2017).

It is noteworthy that this methodology considers that the costs attributed to the reuse of water are exclusively the costs associated with the complementary treatment, distribution and stock units needed to obtain and use reused water with a quality compatible with non-potable industrial uses. The primary costs associated with conventional sewage treatment systems were not attributed, as they are obligations that must be met in order to comply with legal requirements (CNI, 2019; CONAMA, 2005; CONAMA, 2011).

To carry out the estimate and analysis, the following costs were used:

- Acquisition of treated effluent (ATE): The purchase of treated effluent follows a commercial pattern of costs inherent to the process which it underwent in the beneficiation units. The main costs of this process are the chemical elements (CE) needed, energy related to the processing steps (EN), labor (LB) and general system operation (GSO), in addition to the concessionaire profit margin (PM) and local taxes (TX). Thus, we have the Equation (1) below;

$$\text{ATE} = \text{CE} + \text{EN} + \text{LB} + \text{GSO} + \text{PM} + \text{TX} \quad (1)$$

- Complementary treatment for quality adjustment (CTQ): Generally, water does not yet have all the necessary requirements for its use as reuse water, especially if it is reused in more complex industrial processes, thus, it is necessary to complement the initial treatment, usually by chemical processes, aiming at its suitability in terms of elementary standards;
- Primary distribution line (PDL): The transport of reuse water, from the treatment unit to the industrial plant where it will be reused, must be carried out through high pressure adduction lines (HPL), and this process must be carried out with the construction of these units, including their pumping system (PS), maintenance (MAT), and operation (OP), according to Equation (2).

$$\text{PDL} = \text{HPL} + \text{PS} + \text{MAT} + \text{OP} \quad (2)$$

- Final stock (FSK): Finally, the costs of construction, maintenance and operation of water accumulation reservoirs before reuse must be foreseen, these reservoirs must be different from those connected to potable treated water. Thus, the final cost (FC) of the water reuse operation can be estimated, according to Equation (3).

$$\text{FC} = \text{ATE} + \text{CTQ} + \text{PDL} + \text{FSK} \quad (3)$$

Results and discussion

According to the records consulted in the months of June and July 2021, the region has forty concessions for surface and underground catchment for industrial use (seventeen granted by ANA and twenty-three granted by INEA), with a total annual flow of 142,091,523.36 m³/year, in eleven cities, as shown in Table 1. From the analysis of the information obtained, it was possible to verify that the cities of Volta Redonda, followed by Resende, Barra Mansa and Barra do Piraí are those with the largest collected volume, Volta Redonda, accounting for about 84% of all annual volume in the region.

Among all the concessions analyzed, the steel mill Presidente Vargas Plant (PVP) in the municipality of Volta Redonda stands out, accounting for a grant of 119,994,480.00 m³/year.

Table 1 Grants issued by ANA and INEA, and the collected volumes, by cities of RH III

Cities	Industrial grants		Volume granted (m ³ /year)	
	ANA	INEA	ANA	INEA
Barra do Piraí	1	2	4,363,808.64	568,838.16
Barra Mansa	4	4	5,596,440.00	38,336.64
Comendador Levy Gasparian	1	0	2,148,000.00	0
Itatiaia	0	2	0	66,960.00
Paraíba do Sul	1	2	657,000.00	84,780.00
Porto Real	2	2	205,152.00	486,266.40
Quatis	1	0	1,157,108.40	0
Resende	3	8	5,489,424.00	802,703.52
Três Rios	2	0	217,152.00	0
Valença	0	2	0	116,025.60
Volta Redonda	2	1	120,080,328.00	13,200.00
Total	17	23	139,914,413.04	2,177,110.32

Table 2 Estimated population in the cities

Counties	Population (CENSO IBGE, 2010)	Estimated population (2020)
	Total (hab)	
Barra do Pirai	94,778	100,764
Barra Mansa	177,813	184,833
Resende	119,769	132,312
Volta Redonda	257,803	273,988
Total	650,163	691,897

Sanitation data for the region

The municipalities belonging to Hydrographic Region III, in 2020, had an estimated population of 1,162,503 inhabitants (IBGE, 2020), the most populous being Volta Redonda, Barra Mansa, Resende and Barra do Pirai, respectively, Table 2.

Data from the Diagnosis of Water and Sewage Services (SNIS, 2020) indicate that there is treatment for about 49.1% of the sanitary effluent generated in the country. The analysis of data from the four selected cities shows that they have coverage insufficient in relation to the treatment of generated effluents, Fig. 3.

The data above demonstrate that despite the efforts of some municipalities for a wide network of effluent

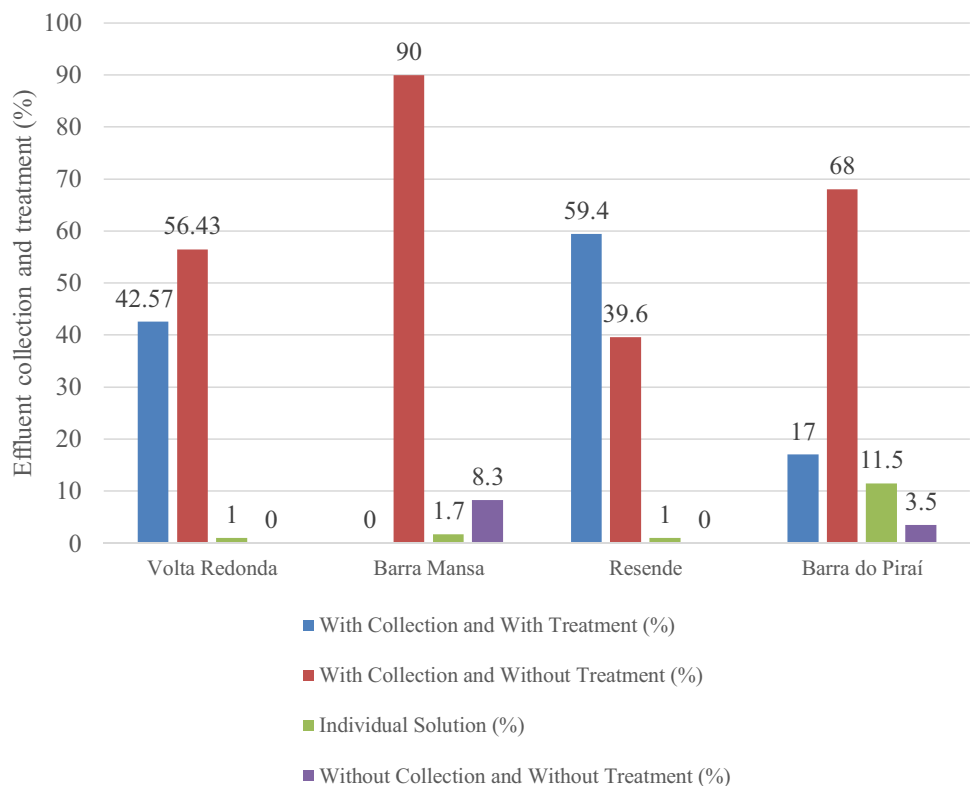
collection, there is still a lot to improve in the treatment given the deadline for reaching the goal of universal service provision, expected in the Legal Framework for Sanitation and to achieve the goals of SDG-06. With investment in collection and treatment services, this untreated effluent could be used by industries to the detriment of water collection in water bodies.

Case study: Presidente Vargas Plant (PVP) — Volta Redonda, Brazil

It is considered one of the largest steel mills in Latin America and has an annual production capacity of 5.8 million tons of steel. The two blast furnaces currently in operation together produce 12,800 tons of pig iron per day. The main production units are coking, sintering, steelmaking, continuous casting, hot rolling, cold rolling, zinc plating, chrome plating and electrolytic tinning (CSN, 2020). Located on the banks of the Paraíba do Sul River, Fig. 4, the company has the grant, no. 1416, of 06/17/2020, valid until 09/24/2023, to capture water in this water body.

The Presidente Vargas Plant currently operates under the Environmental Operating Permit No. IN0002019, of 10/16/2018, an instrument that allows the temporary operation of its activities until full compliance with the obligations established in the Conduct Adjustment Agreement (TAC) 07/2018, signed on September 19, 2018, between Secretary of State for the Environment (SEA), INEA, State

Fig. 3 Effluent collection and treatment data from Volta Redonda, Barra Mansa, Resende and Barra do Pirai



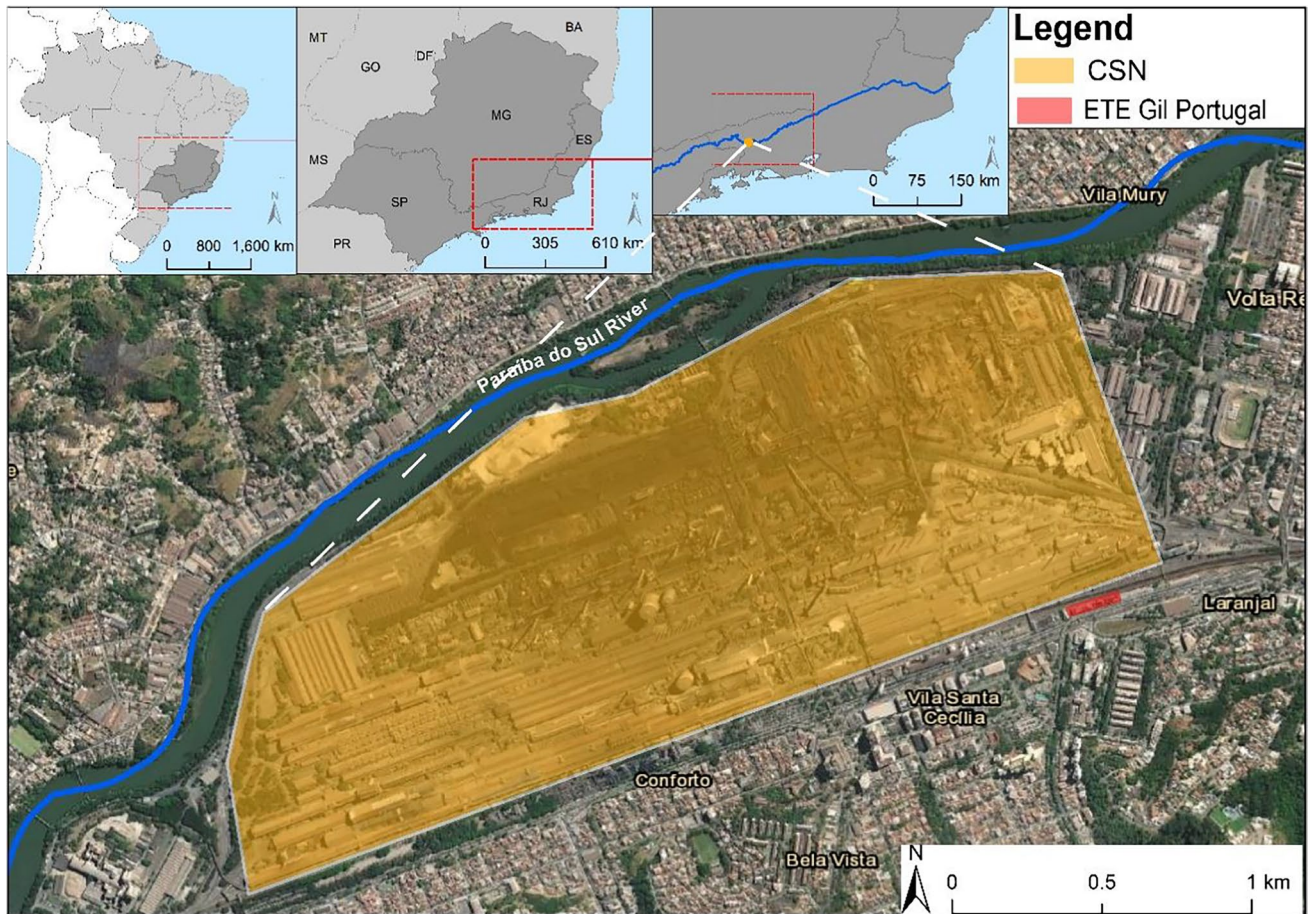


Fig. 4 CSN (President Vargas Plant) and ETE Gil Portugal Location in Volta Redonda

Environmental Control Commission (CECA) and National Steel Company (CSN), with a term of validity of 6 years.

It is noteworthy that this is the fourth instrument signed with CSN, the following instruments were previously signed: (i) TAC with the extinct State Foundation for Engineering and Environment (FEEMA) in 1994; (ii) TAC 026/2010 and Addendum no. 16/2013 (giving a further 2 years for full compliance with the obligations); (iii) TAC 03/2016; and, finally, (iv) TAC 07/2018. Due to the successive non-compliance with the proposed actions, the company was even summoned to shut down the unit but considering the economic and social effects of the shut-down (which did not occur) of the plant, negotiations were started for the execution of a new instrument for adjustments to the PVP to environmental standards. The current Action Plan points out 35 non-conformities, establishing the respective ‘activity proposals’ for adequacy/correction, with affixing deadlines for service. The main non-conformities are related to noise pollution, atmospheric emissions, and pollution of the Paraiba do Sul River, including:

- (i) Sanitary effluents not connected to treatment systems;
- (ii) Failure to monitor parameters that make the internal reuse of effluent inadequate.

After analyzing the Integrated Report (CSN, 2020), it is observed that the company is making investments for the environmental improvement of its processes, including water recycling processes; however, there is no mention in its licensing process of reuse projects that could bring even greater gains and commitments.

Regional effluent treatment stations

The city of Volta Redonda, according to CNI data (2019), is the one with the highest grantable flow in the State of Rio de Janeiro, accounting for 39% of all flows in the State, ahead of widely industrialized municipalities, such as Rio de Janeiro, Duque de Caxias and São João da Barra. The relevance of the federal concession of *Companhia Siderúrgica Nacional* (CSN) is worth highlighting, for this reason,

Table 3 Stations, treatment technologies and ETEs flow in operation in the city of Volta Redonda and Barra Mansa

Treatment station	Treatment technology	Reference flow (Qr) (l/s)
ETE Volta Grande IV	UASB (Upflow anaerobic sludge blanket)	9.3
ETE Gil Portugal	Activated sludge	140
ETE Curral	Activated sludge	25
ETE Bugio	UASB	6.2
ETE Poço	Activated sludge	6.7
ETE Santa Rita	UASB + polishing pond	30
ETE Silvano Streva	UASB + polishing pond	9.2

the city will be the focus of this analysis. The information about the Effluent Treatment Stations were available in the database of the National Water Agency and in the National Sanitation Information System, as shown in Table 3.

Investing in the improvement of effluent treatment systems, with the improvement of processes and treatment capacity in existing stations and/or in the modernization/construction of new stations can be an opportunity to install systems that allow the implementation of initiatives of reuse of treated sanitary effluents.

Analysis of economic feasibility

For the feasibility analysis, Estação Gil Portugal, inaugurated in April 2015, located on Avenida dos Trabalhadores in Volta Redonda, close to *Companhia Siderúrgica Nacional*, as shown in Fig. 4, was selected. The choice was made on the basis of the plant’s effluent capacity (the largest in the region), its treatment technology and location close to a potential user. The ETE has the capacity to treat 140 L of sewage per second, totaling 12 million L/day (Volta Redonda, 2021). To calculate the cost of reuse water, the CNI publication (2019) adopted some assumptions

considering different effluent flows and distances between the station and the consumption points, as shown in Table 4. Power trend, based on two distances and four flow scenarios:

- Alternative A: 4 km discharge line and 5 km gravity line.
- Alternative B: 8 km discharge line and 5 km gravity line.
- Flow Scenarios: 50, 100, 200 and 400 L/second.

Due to the proximity of the Gil Portugal Station to the Presidente Vargas Plant and its flow capacity, a cost estimate of R\$ 1.866 per cubic meter was adopted, which corresponds to approximately US\$ 373.20/m³ As provided for in Brazilian legislation, all users subject to the right to use water must pay for the consumption of this resource. According to Thame et al. (2000), charging should not be thought of only as a way of collecting financial resources to revert the current degradation, but rather as a way of instituting an adequate behavior in relation to the rationalization of water use.

The Paraíba do Sul river basin was a pioneer in charging on the national scene, and the mechanisms and values for charging are established in CEIVAP Deliberation no 218/14 approved by CNRH Resolution no 162/14. Uses for the collection, consumption and release of effluents from users subject to the Granting of the Right to Use Water Resources with water abstraction exceeding 1.0 l/s (CEIVAP, 2021) are charged. The Nacional Water Agency Resolution no. 57/2020 established the calculation of the charge for the use

Table 5 Charge for the use of water resources owned by the Union for the 2021 fiscal year

Types of use	Unit	Value (R\$)
Raw water abstraction	R\$/m ³	0.0249
Raw water consumption	R\$/m ³	0.0499
Effluent release	R\$/kg DBO	0.1746

Table 4 Summary of estimated Capex and Opex costs for the proposed scenarios

Scenarios	Distribution line			Distribution reservoir (m ³)	Capex (R\$)	Opex (R\$/ano)	Cost (R\$/m ³)
	Repres-sion stretch	Strech by gravity	Total length (km)				
50	4	5	9	500	11,670,950	1,095,265	2.283
	8		13				
100	4	5	9	1000	16,579,354	2,199,339	1.866
	8		13				
200	4	5	9	1500	25,808,257	4,109,659	1.586
	8		13				
500	4	5	9	2000	44,991,535	10,468,610	1.357
	8		13				

of water resources owned by the Union for the year 2021, as shown in Table 5:

Based on the analysis, it can be concluded that the investment required to supply treated effluent to consumer industries is still much higher than the amounts paid to basin agencies for the collection of raw water, which, at first, may make any treatment in this sense unfeasible. However, it is necessary to invest in new technologies that can lower costs, improve CAPEX and OPEX calculations for each reality (location, scarcity scenario, strategic importance of the basin, water uses), financial incentive mechanisms for consumer companies, to the sanitation sector and the possibility of forming service centers, such as the model proposed for service at the Capuava Petrochemical Complex, in São Paulo.

Discussion

The steel industry is a major consumer of water resources, and the cooling processes are responsible for a large part of the volume of water collected (França 2012; Sinha et al. 2014; Colla et al. 2017). Of the amount of water consumed, according to Johnson (2003), about 75% of water use is associated with heat transfer operations, 13% with air pollution control and 12% with materials conditioning. In addition to being a large consumer, this industry is extremely important for regional development, especially when analyzing the economic and social dependence of the studied municipalities, in this case Volta Redonda (Lima, 2013

Research has already shown that for a production of 1 ton of steel in India, there is a need for 60 m³ of water, in addition to being associated with high water contamination, in steps such as cooling, descaling and dust cleaning (Fan et al. 2023). A study has already shown that water consumption is not really significant in the steel industry, and its big problem is the disposal of polluted water, so reuse systems have been developed in several parts of the world, aiming at minimizing water resources (Bonetta et al. 2022). The reuse of water in the steel industry involves cooling and desalination aiming at controlling salts and increasing the useful life of the equipment (Colla et al. 2016). A few years ago, the effect of water salinity after steel use was evaluated and its high impact on the shelf life of food when reused without proper treatment to reduce salt concentration was proven (Liu et al. 2013). Research has already shown that the use of techniques such as membranes, chemical treatments, reverse osmosis, and ultrafiltration end up making it possible to control water quality (Voulvoulis 2018).

Authors such as Ferella et al. (2021), Arborea (2017), Jodar-Abellan et al. (2019), Fuchs and Rao (2021), and Jiménez and Asano (2008), defend the balance between economic, social, and environmental values, especially when we

take into account the possible challenges to be faced in a scenario of water scarcity, and the responsibility of all entities involved in the planning of actions considering the multiple uses and priority areas of water. In this context, it is important to discuss the use of wastewater treatment plants, in which effluents are subjected to an additional or complementary treatment to increase or adapt their quality according to use, as an alternative for freshwater collection, minimized the environmental damage resulting from the increased load of wastewater from municipal activities (Pintilie et al. 2016; Guerra-Rodriguez et al. 2020) and the increased business risk of industries located in regions with potential vulnerability water scenario (Jimenez and Asano 2008). This type of reuse has advantages such as: constant flow, reservation of the use of better quality water for non-priority purposes, environmental benefits, and disadvantages, such as lack of regulation, difficult public acceptance, and the presence of new pollutants (Saurí and Arahuetes 2019).

The analysis of the literature allows us to conclude that there is a large field of action, whether in the development of technologies and/or in the dissemination and promotion of actions taken, especially in nations where the scarcity of water resources is already present, in line with economic and political development in the industrial sphere, agriculture, landscape composition or potable reuse (Santos and Mancuso 2003; Angelakis and Gikas 2014; Zhu and Dou 2018; Jodar-Abellan et al. 2019; Cruz and Mierzwa 2020; Guerra-Rodriguez et al. 2020; Moura et al. 2020; Mukherjee and Jensen 2020; Santos et al. 2020; Rodríguez-Villanueva and Sauri 2021). However, for each use, an analysis of the type of effluent to be treated and the final quality of water required is necessary, which generates the need for additional investments in the treatment process when compared to conventional treatment systems, including the lack of public incentive, skilled labor and low national scientific contribution (Subtil et al. 2017). At this point, it is vitally important to define the physical, chemical, and microbiological parameters and criteria, so that the reuse water meets the specific quality conditions and requirements, and the level of treatment (Hespanhol 2002; Jodar-Abellan et al. 2019).

In Brazil, the main success story regarding the reuse of treated effluent is the Aquapolo project, the largest wastewater reuse facility in the southern hemisphere, and the fifth largest of its kind in the world (Chrispim et al. 2020; Silva, 2019; Lima et al. 2018). Inaugurated in 2012, Aquapolo aims to ensure the continuous supply of water to the Capuava Petrochemical Complex, even in situations of scarcity, and to transform sewage, previously treated at ETE ABC, into water for industrial use (use in cooling towers, boilers, among others) at the complex (SABESP, 2012), which also made it possible to increase the availability of drinking water for the Metropolitan Region of São Paulo, since its customers consume about 950 million liters of reuse water

per month. The advanced treatment processes used are disk filters, membrane bioreactor, and reverse osmosis; after the treatment, the reclaimed water is used, mainly for cleaning of cooling towers and boilers. The current capacity is to provide up to 650 L/s of water to the industrial complex (Chrispim et al., 2020; GS Inuima Aquapolo, 2021). According to Obraszka et al. (2019) there are some other specific experiences in Brazil and in the state of Rio de Janeiro, such as the use of reused water for cleaning urban roads, and some industries have already adopted this model on occasion to meet their demands in regions where there is shortage and/or where the cost of drinking water justifies the implementation of treatment technologies. Unfortunately, the same cannot be said for public systems, where investment in favor of reuse systems is not yet seen.

Another experience related to the reuse of effluents was the former Petrochemical Complex of Rio de Janeiro (COMPERJ), actual Gaslub, located in the municipality of Itaboraí, Metropolitan region of Rio de Janeiro, whose main water bodies in the surroundings already have their current availability compromised with local demands and with a commitment to meet external demands in the future (LIMA, 2016). In 2011, INEA issued the Preliminary License (LP) to the project that foresaw the construction of a Production and Industrial Water Station, and an underwater crossing in the Guanabara Bay, being, at the time of its conception, the largest water reuse system project in Brazil. The treated effluent would then be used in steam generation and in cooling towers. The project was considered economically unfeasible and replaced by the supply of water from the backwash of ETA Guandu filters, in order to meet the condition, set out in the licensing process. However, this strategy did not go ahead either and, in 2019, with the execution of the TAC between Petrobras, MPRJ, and SEAS/INEA, some conditions were renegotiated, and as a result, the use of the existing concession of the River Guandu (currently destined to the Refinery) was authorized Duque de Caxias - REDUC), to supply water to the Gaslub Complex, through a pipeline, when it is in operation (INEA, 2021).

It should be noted that in 2021, a protocol of intentions was signed between Petrobras and the Government of the State of Rio de Janeiro to carry out actions and studies for the implementation of an Industrial Complex at the place (FIRJAN, 2021), which raises concerns about the availability of water and future demands, which can put the population's supply at risk, due to pressure on the Guandu system (and consequently on Paraíba do Sul), being essential discussions and investments in technologies that promote efficient water management.

Around the world, we have several examples of water reuse, such as for irrigation purposes, which contributed to the gross consumption of water; this has been developing in countries such as Spain, Italy, and Cyprus. In Gran

Canaria, 20% of all water consumption comes from wastewater, which contributes significantly to irrigation (Voulvoulis 2018). A study in Cyprus has already shown that the targets set for reuse are possible, reaching percentages of 28% of water reuse from industrial activity (Elkiran et al. 2019). In more developed countries, such as the UK, we have that only 0.16% of the total volume of treated wastewater is used within industrial activity, the remaining part is destined for irrigation activities (Shoushtarian and Negahban-Azar 2020). The UK government has been investing heavily in public policies that enable the reuse of water in the country's industrialists. Some European countries that suffer from water availability problems use microfiltration treatment systems followed by reverse osmosis, and have been encouraging companies to increase their participation in appropriate environmental policies, ranging from water reuse and solid waste management (Shamaki et al. 2021). Industrial companies in Israel, for example, have already managed to achieve zero net water consumption, which means that all the water consumed throughout their processes is reused internally, which would be an ideal situation (Al-Mahdawi 2021).

Among the industrial segments, the textile industry in Europe and the food industry in the USA are the ones that have been implementing water reuse processes more quickly in their activities, already demonstrating an efficiency of around 20% in cost reduction in the first 5 years of implementation (Al-Mahdawi 2021). This reduction was only possible due to a strong public policy of tax reduction in this segment. However, the greatest global potential for water reuse is through irrigation activities of plantations, since agribusiness is an important economic sector and demands more than 70% of average water consumption (Basu and Dasgupta 2021). The data obtained in this research may also indicate that the surplus of reused water from the CSN steel mill could be used to irrigate crops in the region close to the city, avoiding the need to build large reservoirs, similar to practices already adopted in some countries, Europeans and Asians.

In terms of economic perspective, international studies have shown the increase in the real feasibility of reusing water, since the costs directed to the capture of drinking water have been increasing, while the costs of effluent treatment, transport, and use of alternative energies in the reuse process has been reducing (Padi et al. 2022). A major obstacle in countries where drinking water still has a low cost and is abundant, is the difficulty of justifying from an economic perspective the need for effective reuse; this is verified in the Brazilian reality. However, the need for preservation and coincident use aimed at future generations is worth highlighting, in addition to the fact that the costs of implementing abstraction systems, increasingly less accessible, are increasing, such as in the capture of groundwater,

which have higher costs, the surface waters (Ghafoori et al. 2022; Qiu et al. 2022). Some regions of the Middle East already make use of water desalination technologies, but it has already been proven in studies that the average cost of this process is higher than the reuse process, which still has a better-quality liquid at the end (Voulvoulis 2018).

Conclusion

Considering the information presented, it was concluded that the state of Rio de Janeiro has a threat of water scarcity that could be aggravated in the coming years, if measures and investments in supply alternatives are not adopted, and improvement in all stages of water management water resources. Among other issues, such as:

- In the case of industries, the role of private companies in investing in actions that seek to improve their processes is notorious in order to reduce funding and intensify internal reuse, whether motivated by economic factors (such as lower tariffs and adaptation to receiving certifications of credits) or by obligations entered into in the environmental licensing processes. For this reason, it is extremely important to define criteria and standardized legislation that allow environmental agencies, from different states, to improve their analysis, including specific reuse license conditions, especially in regions with high urbanization and/or demand for this resource. The character and technical decisions of the processes must be respected, even if these justify greater investments by the entrepreneurs.
- Despite international pressures to universalize effluent collection and treatment services, with the internal investment perspectives after the publication of the New Legal Framework for Sanitation (and the legislation that provides for reuse within the State of Rio de Janeiro), regulation of the subject is still in its initiation and there is a long way to go to make the practice safer from a legal and institutional point of view.
- It is also notorious to emphasize the importance of overpricing the collection of drinking water (in relation to treated raw effluent), training and inspection by environmental agencies, penalizing users (public or private) who pollute water bodies with the release of untreated effluents, aiming to encourage an increase in the percentage of collection and treatment of domestic effluents, in addition to improvements in water distribution networks, reducing associated losses.
- The average water reuse costs obtained, considering the distance between Gil Portugal Station to the Presidente Vargas Plant, was US\$ 373.20/m³. Investment required to supply treated effluent to consumer industries is still

much higher than the amounts paid to government agencies for the collection of raw water, which, at first, may make any treatment in this sense unfeasible. However, in a scenario close to stress and water scarcity, reuse will certainly be a routine and lower cost practice, mainly applied to industries, such as the steel industry, which was the object of this research. It was also observed that there are practices already in use in Brazil regarding the reuse of industrial water.

Future studies must be carried out to assess the feasibility of implementing more universal effluent treatment systems, which are already designed to meet the industrial and other demands of the studied region, expanding non-potable reuse projects in the State of Rio de Janeiro that are limited to on-off activities.

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Data availability The data that support the findings of this study are available on request from the corresponding author A.R.G.A. The data are not publicly available due to containing information that could compromise research participant privacy/consent.

Declarations

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