S&G 16 (2021), pp. 196-213

S&G JOURNAL
ISSN: 1980-5160

QUANTITATIVE EVALUATION OF THE POTENTIAL FOR INDUSTRIAL REUSE FROM THE EFFLUENTS OF FOUR SEWAGE TREATMENT PLANTS IN THE METROPOLITAN REGION OF RIO DE JANEIRO, BRAZIL

Marcelo Obraczka
marcelobraczka@gmail.com
State University of Rio de Janeiro-UERJ, Rio de Janeiro, RJ, Brazil.

André Alcântara Faria
afaria.alcantara@gmail.com
State University of Rio de Janeiro-UERJ, Rio de Janeiro, RJ, Brazil.

Luis Carlos Soares da Silva Jr
lcsoareseng@gmail.com
State University of Rio de Janeiro-UERJ, Rio de Janeiro, RJ, Brazil.

Alfredo Akira Ohnuma Jr
akira@uerj.br
State University of Rio de Janeiro-UERJ, Rio de Janeiro, RJ, Brazil.

Kelly de Oliveira
kogil907@gmail.com
State University of Rio de Janeiro-UERJ, Rio de Janeiro, RJ, Brazil.

Bruno Cabral Muricy
brmuricy@hotmail.com
State University of Rio de Janeiro-UERJ, Rio de Janeiro, RJ, Brazil.

ABSTRACT

Allied to the saturation of conventional supply systems and the pollution of the main water sources, the recurrent situations of droughts and shortages have been affecting the availability of water in many regions of the country, once abundant in water, such as the SE. The present study is part of the development of the necessary knowledge on alternative sources for meeting society's basic water demands. In this case, we focus on the reuse of wastewater to supply industrial demands in the metropolitan region of Rio de Janeiro (RMRJ), since this reuse can contribute to reducing the pressure on already saturated springs and supply systems, saving drinking water for more noble uses. This study aimed to evaluate, in terms of quantity, the potential to meet the demand for reuse water for industrial and non-potable purposes, based on the supply of treated effluent from four sewage treatment plants (STPs Alegria, Penha, Pavuna, and Sarapuí) in RMRJ, whose characteristics, such as location and installed treatment capacity, favor them as potential suppliers of regenerated water. As potential consumers, we considered industries in the transformation sector located within a radius of 10 km from these treatment systems (STPs). The great potential for reuse in the scenarios studied was verified by comparing the installed capacity of secondary treatment systems and the production of regenerated water available at the listed STPs in relation to the industrial water demands of a total of 728 processing companies located in the respective coverage radii defined from each STP. Many of these industries can be served by more than one treatment plant and, in addition, the large availability of potential reuse water supply in relation to demand also indicates the feasibility of meeting the water supply for other sectors and industrial typologies. The most representative sectors for the four STPs, from the point of view of the number of companies, were *22-Rubber/Plastics (rubber artifacts and plastic packaging)*, *25-Metal products (metal structures, machining)*, and *28-Machinery and equipment manufacturing*. From the viewpoint of flow, the most representative were *20-Chemicals (especially petrochemicals/polymer products)* for all the STPs and *30-Manufacture of other transport equipment, except motor vehicles*, only for the Alegria and Penha STPs. Although the four ETE's listed present good potential for supplying reuse water, the Penha STP deserved more emphasis for presenting the highest required flow rate due to the number of companies that can be served in its surroundings, besides already having a reuse water production system in operation since 2007. Despite having a lower available flow rate, in addition to a greater distance in relation to the center of mass of the demands related to the industrial blocks, the Sarapuí STP can also be considered as a priority for being the closest to the largest potential consumption of reuse water identified by the study, i.e., the companies of the REDUC complex.

KEYWORDS: STPs; Effluents; Reuse; Industries; Inventory.

PROPPI / DOT
DOI: 10.20985/1980-5160.2021.v16n2.1727

S&G Journal
Volume 16, Number 2, 2021, pp. 196-213
DOI: 10.20985/1980-5160.2021.v16n2.1727

1. INTRODUCTION

The growing demand for water to supply the population and ensure the development of all economic activities in the country is a challenge in the management of water resources. In this sense, diversifying the sources of supply for industry and other sectors of the economy can help in the search for the much-desired water security (CNI, 2020).

According to Faria (2020), aggravated by the effects of climate change and the pollution of major water sources, recurrent water shortage situations, such as that of 2014/15 in São Paulo (Empinotti *et al.*, 2019) and in the Rio de Janeiro Metropolitan Region (Campos, 2018), considerably affect the availability and water security of strategic regions for the country (Formiga *et al.,* 2015).

According to Rocha (2020), based on data from PERHI (Government of RJ, 2014), it is possible to identify as an aggravating factor that a large part of the Rio de Janeiro Metropolitan Region – notably that located west of the Guanabara Bay – is extremely needy, requiring the import of almost all the water to meet their needs, since the water resources owned by these areas are insufficient to meet the magnitude of the growing demand (Figure 1).

According to Hespanhol (2008), Formiga *et al.* (2015), and Obraczka *et al.* (2019), to face this serious problem, actions and measures are needed for rationalization and conscious use of water as well as the use of alternative non-conventional sources, including rainwater and the reuse of wastewater for less noble and non-potable destinations.

According to authors such as Angelakis and Gikas (2014), Bila *et al.* (2017), and Steflová *et al.* (2018), wastewater reuse is already a current practice in several countries, assuming a more prominent position where there are situations of greater water stress, configuring itself as a relevant alternative source of water supply to conventional systems.

According to Nobre (2013), SABESP meets various industrial demands in the RMSP from the supply of reuse water from the Jesus Neto STP (18 L/s), the Parque Mundo Novo STP (24 L/s), and more recently the ABC STP (650 L/s). The ABC STP is part of the AQUAPOLO enterprise, the most important reuse system in all of Latin America (Machado, 2019; Faria, 2020; and Mierzwa, 2020). According to CNI (2020), this reuse water supply unit had its construction started in 2010 and its operations began in 2012, with the potential to treat up to 0.9 m^3/s of effluents from the ABC STP, serving a condominium of industries through an exclusive reuse water pipeline, with Ø 900mm and length of 16.5 km (Nobre, 2013). In the

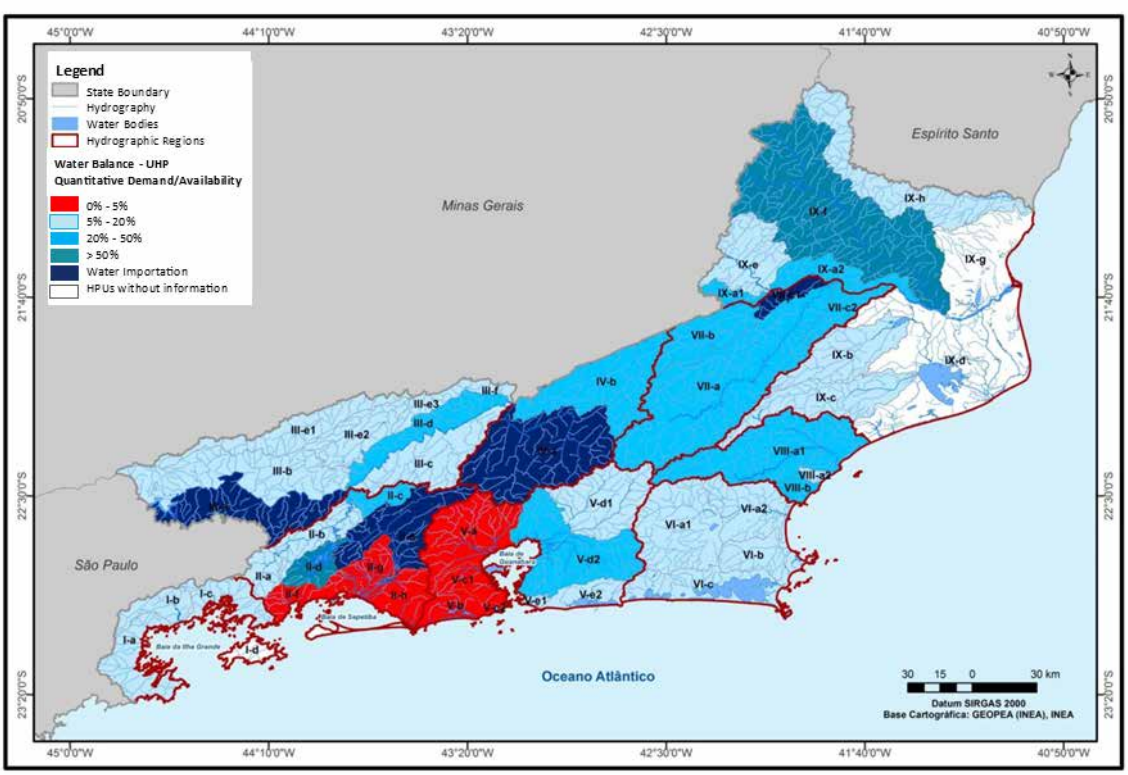

Figure 1. Current consumption demand in relation to water availability by HPU of the State of Rio de Janeiro (Estado do Rio de Janeiro - ERJ). The area in red shows the criticality of RMRJ's situation in its west portion of the Guanabara Bay.

Source: PERHI-RJ (Government of the ERJ, 2014)

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absence of national regulations for using reuse water, based on international experience, SABESP has developed its own internal quality criteria, including the water balance aspect of the plant (PROSAB apud Semura *et al*., 2005).

The investigations of Faria (2020) and Faria *et al.* (2021) carried out in the Rio de Janeiro metropolitan region, considered that in CEDAE's concession area, the main STPs for reuse implementation are Alegria, Penha, Pavuna, and Sarapuí, due to their larger size and strategic location, also based on the priorities listed by CEDAE itself (Rio de Janeiro, 2019). The map with the location of these four STP's, including the respective coverage/service areas of their respective sewage systems/networks is presented in Figure 2.

There are already small reuse water production systems (RWPS) in three wastewater treatment plants in the metropolitan region of Rio de Janeiro (RMRJ): Alegria, Penha, and Deodoro. These systems have a secondary treatment effluent polishing stage, and this post-treatment is basically composed of two phases: simple filtration (in-line) and then disinfection with hypochlorite (Branco, 2016; and Faria, 2020). The reuse water generated from the procedure meets the utilities' internal demands (equipment washing, network unblocking); however, in the case of the Penha STP, part of the reuse water (3,010 m^3) is also supplied to COMLURB to unclog galleries and wash public roads and fairs. Of this part, 363 m^3/month are used internally for polymer dilution, centrifuge cleaning, vehicle and work yard washing, totaling about 3,373 m^3/month (Neto and Oliveira, 2008; Zahner Filho, 2014; and Silva Jr. and Obraczka, 2020).

For some years, in the early 2010s, the RWPS at the Alegria STP provided reuse water to contractors working at Porto Maravilha; however, this system has been deactivated since the end of the contract between these companies and CEDAE (FARIA *et al*., 2021). Table 1 presents some features of the main STPs in the Rio de Janeiro metropolitan region, including the three that have an RWPS (Alegria, Penha, and Deodoro).

Despite these isolated and small-scale RWSP initiatives at the Alegria, Penha, and Deodoro STPs, it can be seen that the reuse of effluents is insignificant in the overall context, amounting to less than 0.5% of the installed capacity (BILA *et al*., 2017; OBRACZKA *et al.*, 2017). Even comparing this installed reuse capacity only with the total treatment flow of the listed STPs, the representativeness increases to only about 0.8%. According to Obraczka *et al*. (2019) and Faria (2020), in practice, this value tends to be even lower since the inflows to the other STPs in the Rio de Janeiro metropolitan region (not included here and which do not have RWSP) must be accounted for. Additionally, the Alegria RWSP is currently deactivated, and the Penha RWSP operates with great idleness (Neto and Oliveira, 2007; Zahner Filho, 2014; Branco, 2016).

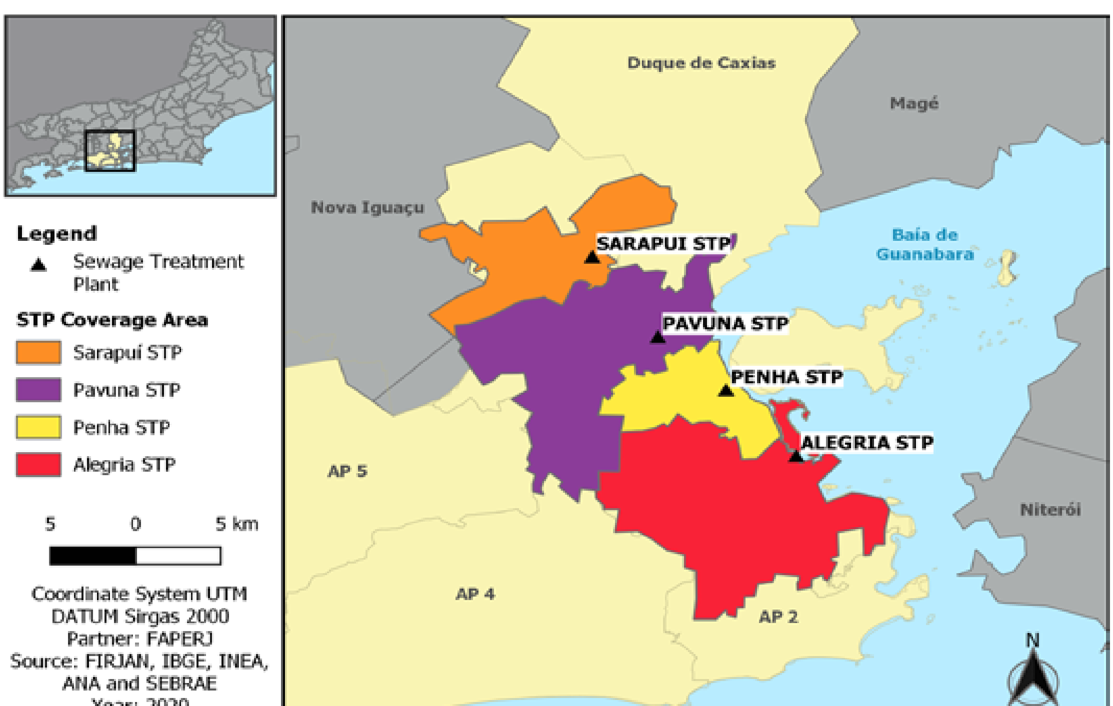

Figure 2. Georeferenced map of the STPs listed as potential generators and their respective coverage areas of the sewage systems.

Source: Faria *et al.* (2021)

Table 1. Main characteristics of potential generators of reuse water in RMRJ

Generating source (STP)	Location	Treatment type	Installed capacity / operational flow	Reuse system / type of polishing?	Installed capacity of the reuse water system (m3/ day)	Reuse Capacity / Installed capacity and Reuse capacity / treatment flow (%)
Alegria	Caju, RJ AP1 (22°52'15"S 43°13'38"W)	Activated sludge by prolonged aeration	216.000/ 132.106	deactivated	1.920	0,9/1,5
Penha	Penha, RJ AP1 (22°49'58"S 43°16'05"W)	Activated sludge by prolonged aeration	93.830/ 66.096	Filtration / Hypochlorite Disinfection	768	0,8/1,2
Sarapuí	Belford Roxo - RJ (22°45'22"S 43°20'43"W)	Chemically assisted primary, Activated sludge	129.600/ 38.880	None	-	0
Pavuna Meriti	Pavuna, RJ (22°49'09"S / 43°18'26"W)	Chemically assisted primary, Activated sludge	129.600/ 19.080	None	-	0
Deodoro	Deodoro, RJ AP5	NEREDA	86.400 (1)/ 67.680	Filtration / Hypochlorite Disinfection	240	0,3/0,4
Sepetiba	Sepetiba, RJ AP5	Activated sludge using extended aeration	5.184	None	-	0
V. Kennedy	V.Kennedy, RJ AP5	Oxidation value	3.370	None	-	0
Pedra de Guaratiba	Pedra de Guaratiba AP5	UASB reactor + submerged aerated biofilter + secondary sedimentation tank	3.456	None	-	0
Santa Cruz (ainda não operacional)	Santa Cruz, RJ AP5	Secondary treatment	21.600	None	-	0
Total	-	-	602.640/ 357.452	-	-	0,4/0,8

Notes: 1 - Flow after expansion (Nereda System) 2 - not yet operational.

Source: Adapted from Bielschowsky (2014), Campos (2018), and Farias (2020)

According to several sources (Araújo *et al., 2017*; BILA *et al.,* 2017; SILVA Jr, 2018; and OBRACZKA *et al.*, 2019), there are several factors that contribute to the current incipient reuse stage, and which hinder its implementation, both in Brazil and in the more specific scenario, in the municipality and metropolitan region of Rio de Janeiro. These factors include: (a) lack of knowledge and of a "culture" of reuse; (b) lack of specific legislation and regulation, especially at the federal level; (c) lack of public policies, planning instruments, and economic incentives; (d) physical obstacles, such as the distance between the main generating poles (larger STPs) and some large potential consumers of reuse water in Rio de Janeiro, such as industries, allied to the capacity/ drainage restrictions of the tanker system to meet these demands. The results of the studies by Silva *et al.* (2016), Araújo *et al.* (2017), Bila *et al.* (2017), and Campos (2018) corroborate this assessment that the geographical proximity between the generator and consumer, combined with the guarantee of flow and quality of industrial water required by the consumer, are the most important requirements for the feasibility and implementation of reuse projects from STP effluents in Rio de Janeiro. Another obstacle mentioned by these authors is the lack of information and a wider and more reliable database to implement reuse on a commercial scale.

In order to fill this gap and provide greater support for decision making and actions to implement reuse in the municipality and the Metropolitan Region of Rio de Janeiro, studies by Campos (2018), Obraczka *et al.* (2017; 2019), Silva Jr. and Obraczka (2020), and Faria (2020) developed an inventory/ mapping of potential generators and users of regenerated

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water, with greater emphasis on its supply by the Alegria STP (Figure 3).

Associated with a database, this mapping included the survey of information on websites of bodies and companies that manage water resources and sanitation, non-governmental organizations, and class or productive sector entities/associations, in addition to consulting technical and scientific papers.

In addition to data on potential suppliers, these surveys included information on possible consumers of regenerated water, considering potential large demands such as those from industries, also covering other large enterprises, such as ports and airports, railroad terminals, and maintenance centers, and large vehicle garages (public transportation and solid waste collection). General data about the study area (RMRJ) were also included, such as the identification and delimitation of municipalities, municipal Planning Areas (PAs), road network, watersheds and sewage system, and the main water bodies.

The results of these studies indicate that the reuse is more feasible primarily from the larger STPs in the metropolitan region of Rio de Janeiro, notably for non-potable and less noble uses, aiming to meet urban and industrial demands.

Due to the concentration of flow and high quality of the effluents treated in the main STPs available in the metropolitan region of Rio de Janeiro, Campos (2018), Silva Jr (2018), and Rocha (2020) corroborate the view that the greatest technical and economic feasibility for reuse is verified from these systems, also for urban and industrial purposes. The reuse of treated sewage is more feasible and economically attractive, especially for the industrial sector, both because of the high consumption of these industries and because of the potable water tariffs adopted by the utilities that make it practically unfeasible for these companies to use water from the public network (Silva Jr. and Obraczka, 2020).

By analyzing the flow rates of the grants by category of water resource use, issued within 25 km of the Alegria, Penha, and São Gonçalo STPs, Rocha (2020) points out a high potential for wastewater reuse in the Rio de Janeiro metropolitan region, highlighting the considerable representativity of the category "Sanitary, industrial, irrigation, recreation" (SI) in relation to the others, except for the year 2018 (Table 2).

Also, according to Rocha (2020), for the three STPs assessed, the representativity of SI has shown a growing trend in recent years, covering more than 80% in total of each analyzed STP and, in general, of all the flow granted. On the other hand, the other categories (CHO - Human consumption and hygiene and others, FI - Food industry) have shown a downward trend.

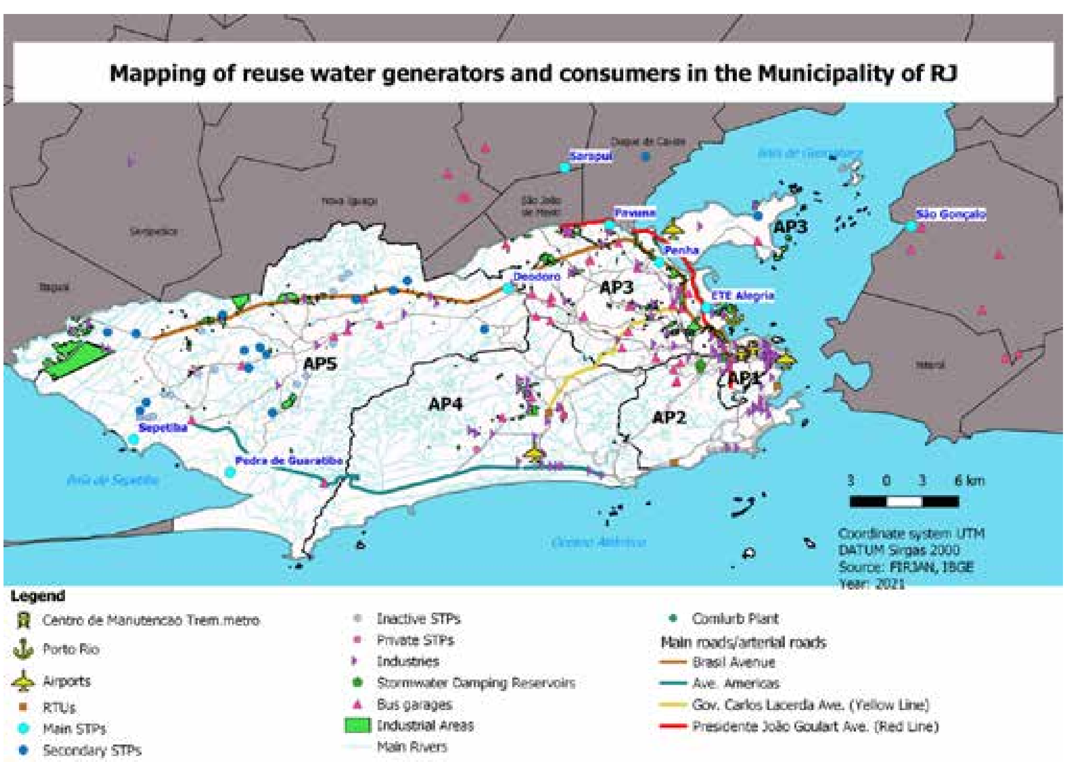

Figure 3. Mapping of reuse water generators and consumers in the city and metropolitan area of Rio de Janeiro, from the Alegria STP
Source: Obraczka *et al.* (2019)

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Table 2. Annual flow rates of the grants by category, issued for enterprises within a 25-km radius of the STPs Alegria, Penha, and São Gonçalo, in m³

STP	Type	2017	2018	2019	Sum	Average	Representativeness of the average in relation to the sum (%)
Alegria	CH	10,654.20	20,163.50	6,228.00	37,045.80	12,348.60	2.60
	CHO	173,367.40	10,795.70	7,270.00	191,433.10	63,811.00	13.40
	FI	6,927.80	7,881.80	4,587.00	19,396.60	6,465.50	1.40
	SD	21,200.00	4,852.80	-	26,052.80	8,684.30	1.80
	SI	134,654.80	21,558.70	999,294.20	1,155,507.70	385,169.20	80.80
	Sum	346,804.20	65,252.60	1,017,379.20	1,429,436.00	476,478.70	100.00
	Average	69,360.80	13,050.50	203,475.80	285,887.20	95,295.70	
Penha	CH	6,436.00	16,973.50	6,228.00	29,637.50	9,879.20	2.10
	CHO	174,114.40	13,116.50	7,598.80	194,829.60	64,943.20	13.80
	FI	6,927.80	2,846.60	5,374.20	15,148.60	5,049.50	1.10
	SD	21,200.00	4,852.80	-	26,052.80	8,684.30	1.80
	SI	133,772.40	22,542.30	988,934.30	1,145,249.00	381,749.70	81.20
	Sum	342,450.60	60,331.70	1,008,135.30	1,410,917.60	470,305.90	100.00
	Average	68,490.10	12,066.30	201,627.10	282,183.50	94,061.20	
São Gonçalo	CH	7,784.40	4,135.00	7,358.40	19,282.80	6,427.60	1.50
	CHO	171,000.00	4,665.00	9,492.20	185,157.20	61,719.10	14.50
	FI	6,720.00	6,624.00	2,505.60	15,849.60	5,283.20	1.20
	SD	10,800.00	-	-	10,800.00	3,600.00	0.80
	SI	49,309.20	3,034.00	990,632.40	1,042,975.60	347,658.50	81.90
	Sum	245,613.60	18,458.00	1,009,988.60	1,274,065.30	424,688.40	100.00
	Average	49,122.70	3,691.60	201,997.70	254,813.10	84,937.70	

Legend: CH (Human consumption and hygiene); CHO (Human consumption, hygiene, and others); FI (Food industries); SD (Sewage disposal); SI (Sanitary, industrial, irrigation, recreation).

Source: Adapted from Rocha (2020)

Based on research grounded on the georeferencing of data from a specific generator (the Alegria STP) and potential consumers of regenerated water in its surroundings, Silva Jr. and Obraczka (2020) identified a cluster of concrete batching plants (CBPs) in the Caju region that presents great technical and economic feasibility for supplying industrial water for mixing, from the existing RWPS at the Alegria STP (Figure 4).

Faria (2020) unfolded from the initial inventory of Campos (2018), adopting the same premise regarding the maximum radius limit of 10 km for reuse feasibility, considering, though, four STPs (Alegria, Penha, Pavuna and Sarapuí). In the work of Faria (2020), more information was added regarding potential consumers in the metropolitan region of Rio de Janeiro, emphasizing the estimated demands for industrial water from sectors of companies considered as more consumptive, specifically the transformation industries (CNI, 2017; ANA, 2019; Faria, 2020).

Figure 5 presents the georeferenced locations of the four main generators (Alegria, Penha, Pavuna and Sarapuí STPs) and the potential consumers of reuse water adopted by the work referenced above (processing industries) (Faria, 2020).

The research showed that the available treatment flows in the four evaluated STPs (estimated at 569030 m³/day) could meet the total industrial water demands of the 728 companies listed as potential consumers, estimated at about 135777 m³/day. Due to the proximity between potential suppliers and consumers, the mapping/inventory also indicated that many companies can be served by reuse water from more than one STP (Faria *et al.*, 2021).

The general objective of the present work was to continue the analysis of the potential for using Reuse Water for non-potable industrial purposes in the metropolitan region of Rio de Janeiro, still under the quantitative aspect. For this

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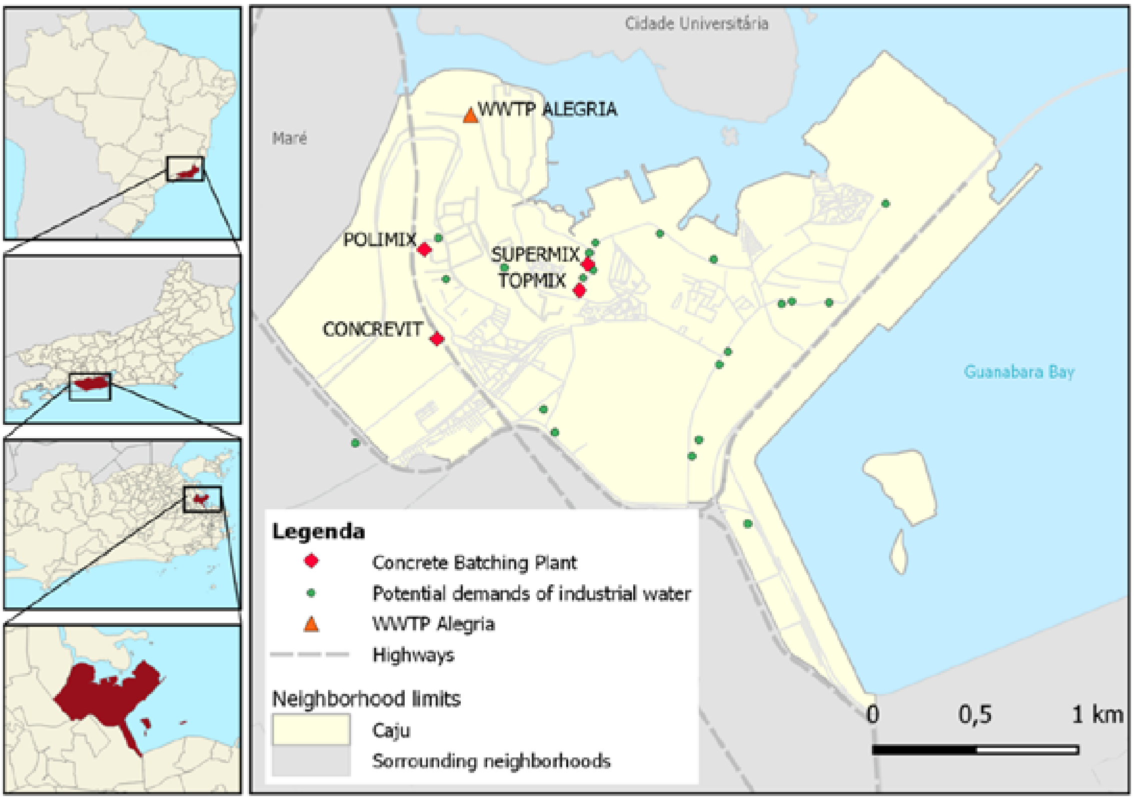

Figure 4. Georeferenced map of potential consumers of reuse water from the RWPS of the Alegria STP, Caju - RJ

Source: Silva Jr and Obraczka (2020)

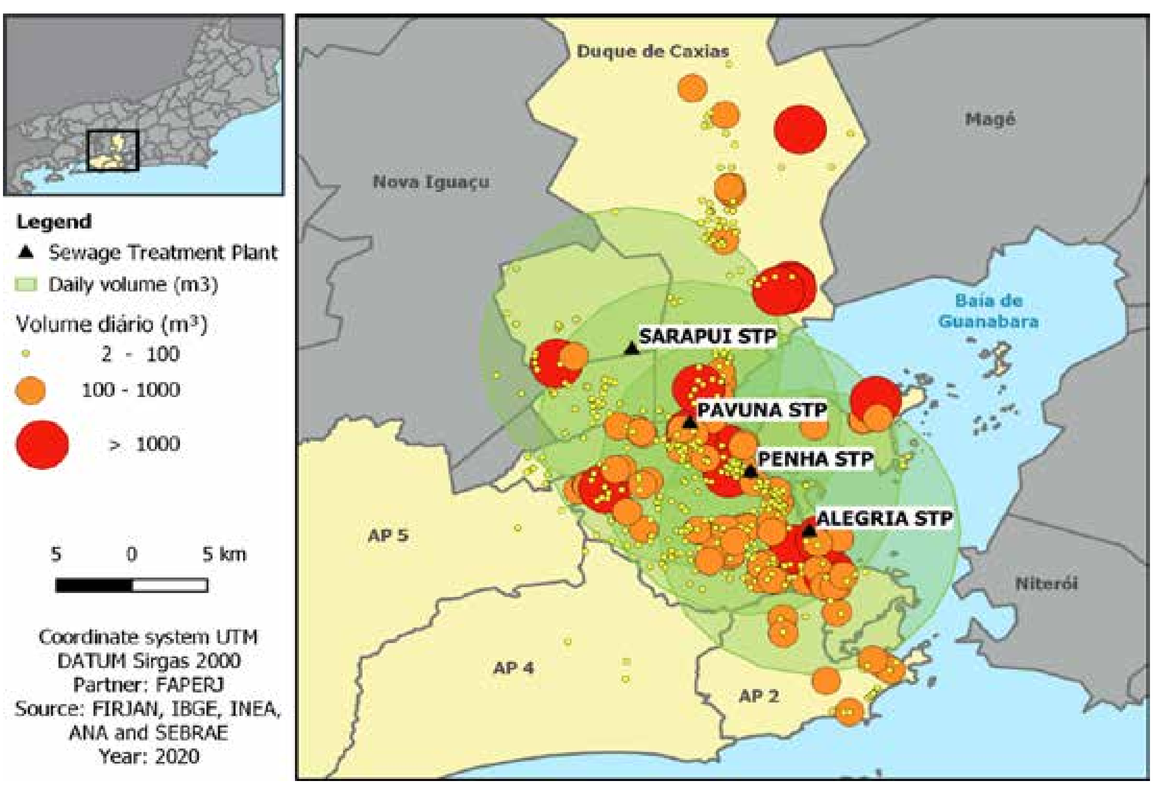

Figure 5. Georeferenced map of generators (Alegria, Penha, Pavuna and Sarapuí STPs) and potential consumers of their reuse water, by volume/daily demand ranges

Source: Faria (2020)

purpose, the inventory/mapping of Faria (2020) was deepened, analyzing the potential to serve the sets of companies in the manufacturing sector located within a radius of 10 km from each of the four prioritized STPs (Penha, Pavuna, and Sarapuí STPs, besides Alegria STP).

2. METHODS

The assumptions and results of the work developed by Campos (2018), Obraczka *et al*. (2019), Faria (2020), and Faria *et al*. (2021) were used as a basis for characterizing the main generators of reuse water, whether effective or potential, focusing on the treatment plants Alegria, Penha, Sarapuí, and Meriti, all operated by the State Company for Water and Sewage of Rio de Janeiro – CEDAE (*Companhia Estadual de Águas e Esgotos do Rio de Janeiro*). These systems were adopted according to the priorities defined by CEDAE, as detailed in the Agreement signed with UERJ to develop studies to implement reuse in the Rio de Janeiro metropolitan area (RIO DE JANEIRO, 2019).

To locate and characterize potential consumers of reuse water in the study area, identifying the water demands specifically for the blocks of industries located in the respective areas of influence of each of the four STPs considered, assumptions and results of the research of Faria (2020) and Faria *et al.* (2021) were used. Based on data from the FIRJAN Industrial Registry (2016), these studies considered only the enterprises in the transformation industry sector (CNAE 2.0 division), located within a 10-km radius around the STPs and prioritized by the research. The required flow rates were estimated based on INEA (2020) and on the water consumption indices by industries, made available by the ANA (2017) study.

Considering each of the four wastewater treatment plants adopted and their respective areas of influence defined within a 10 km radius, it was then possible to evaluate the profile of water demand fulfillment for the blocks of companies listed as potential consumers of reused water, per STP, from a quantitative and comparative point of view. The overlapping of areas of influence of the STPs was verified, as for example several companies that could be served by reuse water from more than one STP, i.e., industries and their respective demands, which were computed by the present study in all possible service alternatives.

To support the analysis and comparison as to the higher or lower potential, indexes were also calculated, such as: a) required flow rate in relation to the number of industries in the area of influence considered for each STP; b) required flow rate regarding nominal capacity and treatment flow rate; and c) treatment flow rate regarding nominal flow (capacity) for each STP.

For the development of the research, Excel and QGIS 3.14.16 ‘Pi’ tools were used, with the aid of resources such as the extension to the base maps and the project’s feasibility rays, generating spreadsheets, graphs, and corresponding maps.

3. RESULTS AND DISCUSSION

Figure 6 presents the georeferenced location of potential generators and consumers of reuse water in the areas under study, by industrial typology, within the manufacturing industry sector, respecting the respective radius limits of 10 km, highlighting the closest regions to each analyzed STP.

Each potential source of reuse water (STP) was analyzed separately, computing all the estimated industrial water demands of the companies located within its influence radius. It can be seen that the areas defined by the 10-km radius limit from each STP overlap with the areas of influence of other STPs involved in the study: Sarapuí STP (also covering Pavuna STP); Pavuna STP (also covering Penha and Sarapuí STPs); Penha STP (also covering Alegria and Pavuna STPs) and Alegria STP (also covering Penha STP).

As already sustained by Faria (2020), there is an overlap of demands in some cases, i.e., there are many industries registered by the study that can be served by more than just one source (STP). This availability can be considered as another favorable aspect for the implementation of reuse since it provides the potential consumer with a 2nd option for water supply. The results of the quantitative inventory are presented below for each of the four STPs prioritized by the research.

Alegria STP

Table 3 presents the summary table by CNAE 2.0 division and respective typologies, discriminating the number of enterprises and average daily flow required from industries located within a 10-km radius from Alegria STP.

Within the 10-km radius from the Alegria STP, in terms of quantity of industries, the following divisions stood out: 14 - Clothing; 22 - *Rubber/Plastic (rubber artifacts and plastic packaging)*; 25 - Metal products (metal structures, machining), and 28 - *Machine and equipment manufacturing*. Together, they represent about 50% of the total number of companies assessed, with 14 - *Apparel manufacturing* being the most representative of all.

In terms of required outflow, the divisions 14 - *Clothing*, 20 - C*hemical Products (especially petrochemical/polymer products)*, and 30 - *Manufacture of other transport equipment except motor vehicles stand out*, representing in total

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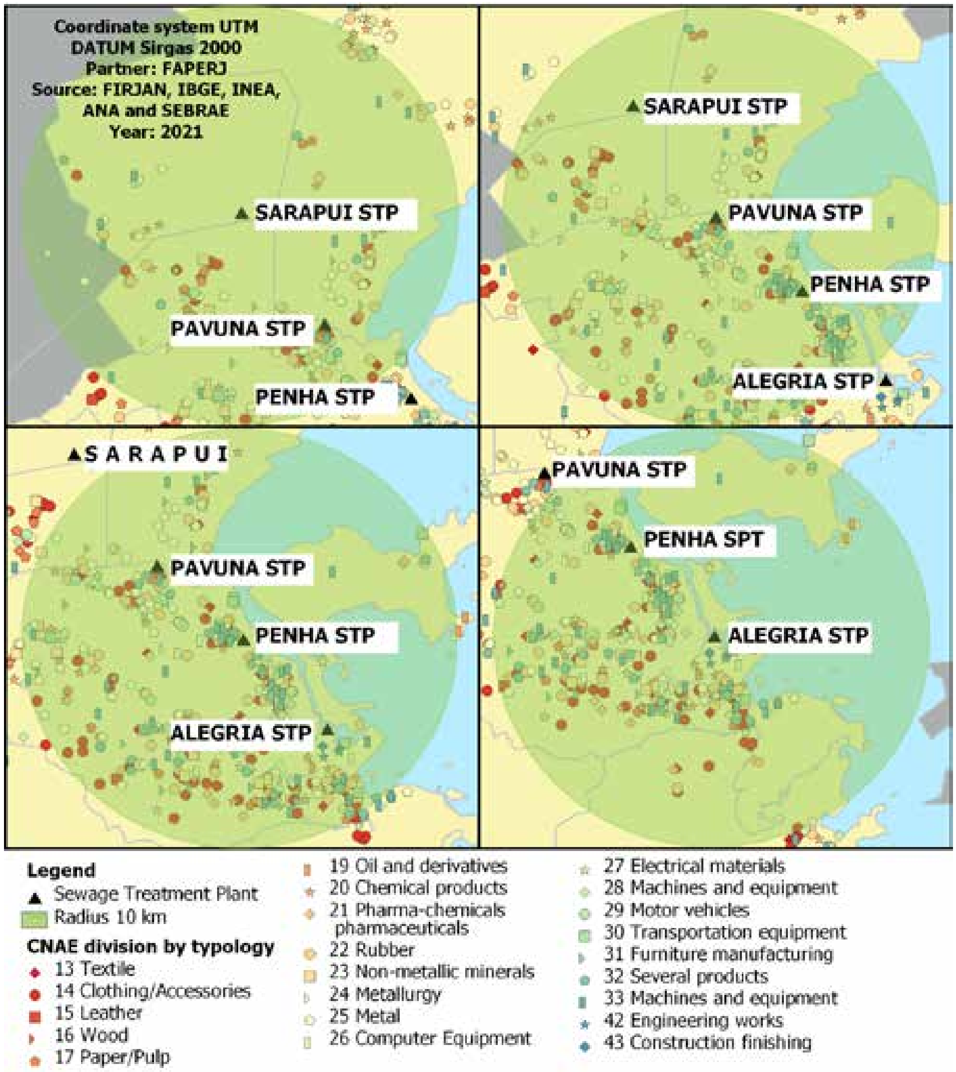

Figure 6. Georeferenced map of potential generators and consumers of reuse water, by industrial typology, for each adopted STP (Alegria, Penha, Pavuna and Sarapuí)

Source: The authors

about 55% of the total demand of the companies in the listed area.

It was also observed that only division 14 - *Clothing* presents a greater representation both in terms of number of companies and required flow. On the other hand, even representing only 1% of the total number of industries, the division 30 - *Manufacture of other transport equipment, except motor vehicles*, is responsible for 17%, that is, about 1/3 of the largest demands of reused water in the studied scenario.

As they are not included in the Transformation sector, the potential demands from several concrete batching plants (CBPs) around the Alegria STP were not computed in this study.

Nevertheless, these companies have great feasibility to be fully serviced, both from a quantitative and qualitative aspect, as highlighted in Silva Jr. and Obraczka's (2020) research, based on data from Zahner Filho (2014).

As a parameterization, according to these same authors, the summed demands of the four CBPs located within a radius of only 2 km from the Alegria STP correspond to about 300 m^3/day, i.e., about only 0.8% in relation to the total demand flow for the sector (Table 2) and 16% in relation to the installed capacity of the RWPS (1,920 m^3/day).

It is worth noting that the RWPS is currently deactivated, and all effluent treated at a secondary level by Alegria STP is fully discharged into the Cunha Canal, which in turn flows into Guanabara Bay.

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Table 3. Summary table of industries by CNAE 2.0 division and respective typologies, located within a 10-km radius from Alegria STP

Item	CNAE Division	Typology	Number of Industries	Percentage in relation to the total number	Flow m3/day	Percentage in relation to total flow
1	13	Textile manufacturing	14	4%	2317.8	6%
2	14	Manufacture of clothing and accessories	71	18%	6174.1	16%
3	15	Leather preparation and manufacture of leather goods, travel goods and footwear	4	1%	939.9	3%
4	16	Manufacture of wood products	2	1%	8.8	*
5	17	Manufacture of pulp, paper, and paper products	14	4%	424.1	1%
6	19	Manufacture of coke, petroleum products and bio-fuels	3	1%	807.1	2%
7	20	Manufacturing of chemical products	28	7%	7642.6	20%
8	21	Manufacturing of chemical and pharmaceutical products	22	6%	1489.5	4%
9	22	Manufacture of rubber and plastic material products	38	10%	281.2	1%
10	23	Manufacture of plastic products	12	3%	1859.1	5%
11	24	Manufacture of non-metallic mineral products	10	3%	2655.7	7%
12	25	Manufacture of metal products, except machinery and equipment	37	9%	720.3	2%
13	26	Manufacture of metal products, except computer machinery and equipment, electronic and optical products	12	3%	117.6	
14	27	Manufacture of machinery, apparatus, and electrical material	9	2%	126.8	
15	28	Machinery and equipment manufacturing	35	9%	1169.9	3%
16	29	Manufacturing of motor vehicles, trailers, and bodies	5	1%	43.9	*
17	30	Manufacture of other transport equipment, except motor vehicles	4	1%	6337.5	17%
18	31	Furniture manufacturing	16	4%	58.6	*
19	32	Manufacture of miscellaneous products	28	7%	2451.1	7%
20	33	Maintenance, repair and installation of machinery and equipment	27	7%	1525.1	4%
21	42	Other civil engineering works not previously specified	3	1%	223.2	1%
22	43	Other construction finishing works	1	*	57.3	*
		TOTAL	395	100%	37431	100%

Note: * values of less than 0.5%.

Source: The authors

It is also important to point out that this idle capacity (at least 132,106 m³/day - Table 1) could easily supply the industrial water demands of a block with the 3rd largest number of transformation sector companies (395) per STP found by the research, among the four scenarios/STPs evaluated, and which also corresponds to the 2nd largest estimated required flow (55,179.3 m³/day), behind only Penha STP.

Penha STP

Table 4 presents the summary table by CNAE 2.0 division and respective typologies, discriminating the number of enterprises and average daily flow required from industries located within a 10-km radius from the Penha STP.

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Within the 10 km radius from the Penha STP, in relation to the quantity of industries, the following divisions stand out: 14 - *Clothing*; 20 - *Chemical products manufacturing*; 22 - *Rubber/Plastics (rubber artifacts and plastic packaging)*; 25 - *Metal products (metal structures, machining)*; and 28 - *Machine and equipment manufacturing*, which represent about 60% of the total companies evaluated.

In terms of demanded flow, the divisions 14 - *Clothing*, 20 - *Chemical Products (especially petrochemical/polymer products)*, and 30 - *Manufacture of other transport equipment, except motor vehicles* stand out, representing 59% of the demand required in the listed area.

It was found that 517, i.e., 71% of the 728 industries selected by the filters/criteria adopted by this research to de-

Table 4. Summary table of industries by CNAE 2.0 division and respective typologies, located within a 10-km radius from Penha STP

Item	CNAE Division	Typology	Number of Industries	Percentage in relation to the total number	Flow m3/day	Percentage in relation to total flow
1	13	Textile manufacturing	17	3%	2747.5	5%
2	14	Manufacture of clothing and accessories	74	14%	7632.7	14%
3	15	Leather preparation and manufacture of leather goods, travel goods and footwear	8	2%	1404.2	3%
4	16	Manufacture of wood products	2	*	8.8	*
5	17	Manufacture of pulp, paper, and paper products	18	3%	683.5	1%
6	19	Manufacture of coke, petroleum products and biofuels	2	*	860.4	2%
7	20	Manufacturing of chemical products	45	9%	11458.7	21%
8	21	Manufacturing of chemical and pharmaceutical products	22	4%	1544.9	3%
9	22	Manufacture of rubber and plastic material products	56	11%	677.8	1%
10	23	Manufacture of plastic products	17	3%	2705.1	5%
11	24	Manufacture of non-metallic mineral products	11	2%	3953.9	7%
12	25	Manufacture of metal products, except machinery and equipment	72	14%	1327.3	2%
13	26	Manufacture of metal products, except computer machinery and equipment, electronic and optical products	12	2%	117.6	*
14	27	Manufacture of machinery, apparatus, and electrical material	11	2%	219.6	*
15	28	Machinery and equipment manufacturing	45	9%	1420	3%
16	29	Manufacturing of motor vehicles, trailers, and bodies	7	1%	51.2	*
17	30	Manufacture of other transport equipment, except motor vehicles	7	1%	13498.5	24%
18	31	Furniture manufacturing	24	5%	105.2	*
19	32	Manufacture of miscellaneous products	32	6%	2940.3	5%
20	33	Maintenance, repair and installation of machinery and equipment	31	6%	1541.8	3%
21	42	Other civil engineering works not previously specified	3	1%	223.2	*
22	43	Other construction finishing works	1	*	57.3	*
		TOTAL	517	100%	55180	100%

Note: * values lower than 0.5%.

Source: The authors

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DOI: 10.20985/1980-5160.2021.v16n2.1727

fine potential consumers are located within a 10 km radius from the Penha STP. As far as flow is concerned, the demand required (52,345.2 m^3/day) is also the largest among the four STPs and the respective companies located in their areas of influence, representing about 30% of the total computed.

Besides its strategic location in relation to potential consumers of reuse water in its surroundings, it can be seen that the Penha STP is located near important arteries/roads such as Avenida Brasil and the Rio-Niterói Bridge, facilitating the transportation/outflow of reuse water production.

It is, therefore, a generator pole of regenerated water to be prioritized, considering that it already has a RWPS, pioneer in Rio de Janeiro and operating since 2007, which has been supplying reuse water to COMLURB for washing public roads and fairs in the city (Netto and Oliveira, 2008; Faria, 2020; Rocha,2020).

It is worth noting that the installed capacity of RWPS represents only 0.8% and 1.2% of the total capacity and total treatment flow of the Penha STP, respectively, and the actual water production of RWPS represents only 16% of the

Table 5. Summary table of the industries per CNAE 2.0 division and respective typologies, located within a radius of 10 km from Pavuna STP

Item	CNAE Division	Typology	Number of Industries	Percentage in relation to the total number	Flow m3/day	Percentage in relation to total flow
1	13	Textile manufacturing	12	3%	1877.2	6%
2	14	Manufacture of clothing and accessories	51	12%	6039.4	19%
3	15	Leather preparation and manufacture of leather goods, travel goods and footwear	6	1%	1214.7	4%
4	16	Manufacture of wood products	1	0%	3.1	*
5	17	Manufacture of pulp, paper, and paper products	26	6%	1016.5	3%
6	19	Manufacture of coke, petroleum products and biofuels	0	0%	0	0%
7	20	Manufacturing of chemical products	42	10%	10594.8	34%
8	21	Manufacturing of chemical and pharmaceutical products	11	3%	575.6	2%
9	22	Manufacture of rubber and plastic material products	45	10%	587	2%
10	23	Manufacture of plastic products	17	4%	1829	6%
11	24	Manufacture of non-metallic mineral products	11	3%	2072.2	7%
12	25	Manufacture of metal products, except machinery and equipment	70	16%	1337.5	4%
13	26	Manufacture of metal products, except computer machinery and equipment, electronic and optical products	8	2%	70.8	*
14	27	Manufacture of machinery, apparatus, and electrical material	9	2%	198.1	1%
15	28	Machinery and equipment manufacturing	41	10%	1338.2	4%
16	29	Manufacturing of motor vehicles, trailers, and bodies	8	2%	55.4	0%
17	30	Manufacture of other transport equipment, except motor vehicles	4	1%	726	2%
18	31	Furniture manufacturing	18	4%	87.3	*
19	32	Manufacture of miscellaneous products	23	5%	1429.7	5%
20	33	Maintenance, repair and installation of machinery and equipment	27	6%	564.7	2%
21	42	Other civil engineering works not previously specified	0	0%	0	0%
22	43	Other construction finishing works	0	0%	0	0%
		TOTAL	430	100%	31617.3	100%

Note: * values lower than 0.5%.

Source: The authors

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installed reuse capacity of this STP (Netto and Oliveira, 2008; Zahner Filho, 2014; Faria, 2020).

Hence, this situation indicates the existence of a large idle capacity that can be better exploited, generating more revenue, without necessarily demanding large investments/costs for the Concessionaire (Branco, 2016; Silva Jr and Obraczka, 2020; Obraczka *et al*., 2020).

Pavuna STP

Table 5 presents the summary chart by CNAE 2.0 division and respective typologies, detailing the number of enterprises and average daily flow required from industries located within a 10 km radius from Pavuna STP.

Within the 10 km radius from the Pavuna STP, in terms of quantity of industries, the following divisions stand out: 14 - *Clothing*; 20 - *Chemical Products (especially petrochemical/polymer products)*; 22 - *Rubber/Plastics (rubber*

Table 6. Summary table of the industries per CNAE 2.0 division and respective typologies, located within 10 km of the Sarapuí STP

Item	Divisão CNAE	Tipologia	Número de Indústrias	Porcentagem relação ao número total	Vazão (m3/dia)	Porcentagem em relação a vazão total
1	13	Textile manufacturing	8	4%	1768.3	3%
2	14	Manufacture of clothing and accessories	19	8%	2207.8	4%
3	15	Leather preparation and manufacture of leather goods, travel goods and footwear	3	1%	426.4	1%
4	16	Manufacture of wood products	0	0%	0	0%
5	17	Manufacture of pulp, paper, and paper products	13	6%	431.2	1%
6	19	Manufacture of coke, petroleum products and biofuels	1	*	32208	62%
7	20	Manufacturing of chemical products	29	13%	9404.8	18%
8	21	Manufacturing of chemical and pharmaceutical products	3	1%	85.5	*
9	22	Manufacture of rubber and plastic material products	29	13%	471.1	1%
10	23	Manufacture of plastic products	8	4%	1017.7	2%
11	24	Manufacture of non-metallic mineral products	8	4%	1689.9	3%
12	25	Manufacture of metal products, except machinery and equipment	51	22%	944.3	2%
13	26	Manufacture of metal products, except computer machinery and equipment, electronic and optical products	0	0%	0	0%
14	27	Manufacture of machinery, apparatus, and electrical material	4	2%	138.6	*
15	28	Machinery and equipment manufacturing	19	8%	452.7	1%
16	29	Manufacturing of motor vehicles, trailers, and bodies	4	2%	16.4	*
17	30	Manufacture of other transport equipment, except motor vehicles	2	1%	336	1%
18	31	Furniture manufacturing	8	4%	46.9	*
19	32	Manufacture of miscellaneous products	7	3%	579.3	1%
20	33	Maintenance, repair and installation of machinery and equipment	11	5%	120.4	*
21	42	Other civil engineering works not previously specified	0	0%	0	0%
22	43	Other construction finishing works	0	0%	0	0%
		TOTAL	227	100%	52345.2	100%

Note: * values lower than 0.5%.

Source: The authors

artifacts and plastic packaging); 25 - *Metal Products (metal structures, machining)*; and 28 - *Machine and equipment manufacturing*.

The divisions 22, 25, and 28 no longer translate their representativity in terms of quantity to representativity in flow, highlighting in this aspect the divisions: 14 - *Clothing* and 20 - *Chemicals (especially, petrochemicals/polymer products)*, which represent 54% of the demand required in the listed area.

Although the Pavuna STP has the second largest number of industries (430) in its area of influence that can be served by reuse water, the total flow demanded by these companies (31,617.3 m^3/day) is the smallest among all four STPs evaluated by the research, representing a little less than half the flow required for both Penha and Sarapuí STPs.

Sarapuí STP

Table 6 presents the summary table by CNAE 2.0 division and respective typologies, detailing the number of enterprises and average daily flow required of the industries located within 10 km of the Sarapuí STP.

In the 10 km radius from the Sarapuí STP, in terms of quantity of industries, the following divisions stand out: 20 - *Chemical Products (especially petrochemical/polymer products)*; 22 - *Rubber/Plastic (rubber artifacts and plastic packaging)*; and 25 - *Metal Products (metallic structures, machining)*.

In terms of demanded flow, the division 19 - *Manufacture of coke, petroleum products and biofuels* stands out. Despite having only one industry with this typology (division), the water flow required represents 62% of all the estimated demand for the companies located in the area of influence listed from the Sarapuí STP.

It is also worth mentioning the division 20 - *Chemical Products (especially petrochemicals/polymer products)*, with 18% of the total estimated flow, which added to the division 19 - *Manufacture of coke, petroleum products and biofuels*, represents 80% of the total flow demanded for the companies registered/situated in the delimited area. The demands of these typologies represent approximately 60% of the total flow required by all the industries computed in the study.

It can also be observed that despite a smaller amount of industries (228) located in its area of influence (10-km radius), if compared to the other STPs, the total water flow demanded is quite representative, second only to the flow required in the Penha STP's area of influence scenario.

Considering the aspect of interconnection and transport of water between generators and consumers, this higher ratio between flow and number of companies can be configured as a positive indicator regarding the viability of reuse from the Sarapuí STP. From this point of view, the Alegria and Penha STPs present close and intermediate values, while Pavuna STP is the one that presents the lowest "reuse water outflow per industrial unit per day" ratio. Table 7 presents a compilation of the general results obtained for the four STPs in meeting the demands of the industries listed by the research in their respective areas of influence.

It is also worth noting the high potential to meet the demands in all four STPs, due to the difference between their

Table 7. Compilation of the results obtained for the four STPs and potential consumers of reuse water in their surroundings/areas of influence

Item	ETE Alegria	ETE Penha	ETE Pavuna	ETE Sarapuí
1. Total number of industries (un)	395	517	430	227
2. Preponderant division/sector (number of industries)	14,22,25,28	14,20,22,25,28	14,20,22,25,28	20,22,25
3. Total flow required (m3/day)	37,431	55,179.3	31,617.3	52,345.2
4. Division/Main sector (flow)	14,20,30	14,20,30	14,2	19,2
5. Ratio between items 3 and 1 (m3/industry*day)	94.8	106.7	73.5	230.6
6. Installed capacity (m3/day)	216,000	93,830	129,600	129,600
7. Treatment flow (m3/day)	132,106	66,096	19,080	38,880
8. Ratio between items 7 and 6 (expansion capacity) (%)	38.8	29.6	85.3	70.0
9. Ratio between items 3 and 6 (%)	17.3	58.8	24.4	40.4
10. Ratio between items 3 and 7 (%)	28.3	83.5	165.7	134.6

Legend: 14-Clothing; 19-Manufacture of coke, petroleum products, and biofuels; 20-Chemicals (especially petrochemicals/polymer products); 22-Rubber/Plastics (rubber products and plastic packaging); 25-Metal products (metal structures, machining); 28-Machinery and equipment manufacturing; 30-Manufacture of other transport equipment, except motor vehicles.

Source: The authors

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installed capacity and treatment flow. Ranging from a minimum of 40% at the Alegria STP to a maximum of 85% at the Pavuna STP, this expansion capacity can be considered as another potential for the implementation of reuse systems in the metropolitan region of Rio de Janeiro.

Considering the installed capacity as the basis for the evaluation, all the STPs are able to meet their respective demands with a clearance that varies from a maximum of about 83% (Alegria STP) to a minimum of 41% (Penha STP). If, however, only the (operational) treatment flow is adopted as an assumption, this availability is reduced to 72% (Alegria STP) and 41% (Penha STP), becoming non-existent at both Sarapuí and Pavuna STPs. This observation points to the need to expand the service and the sewage collection from the corresponding drainage basins, in order to increase the affluent flows, notably the Sarapuí and Pavuna STPs, as a precondition for implementing reuse on a more comprehensive scale in their respective areas of influence. However, especially for these two STPs, the size of their respective sewage basins (Figure 3) shows the existence of a great potential for growth of the inflow. This can be inferred due to two of the basic characteristics of these areas/basins: they have a large population and demographic density, having on the other hand a low coverage/service of the collecting system and local sewage system.

The chart in Figure 7 shows the installed capacities (nominal) of the secondary treatment plants Alegria, Penha, Pavuna, and Sarapuí, and of the reuse water production systems (RWPS) of Alegria and Penha STPs. Besides the daily flow rates required by the industries that were identified as potential consumers of reuse water and located within a 10 km radius of influence from each assessed STP, the chart includes the respective balances (capacity - demand) available.

Although not part of the scope of this study, it is worth highlighting some aspects related to the quality of the effluents treated at the evaluated STPs. To meet the restrictions of the environmental legislation of Rio de Janeiro regarding the limits of parameters for effluent discharge into water bodies, including DZ 215 (one of the most restrictive in the country), the STPs have secondary treatment processes, such as activated sludge. These systems are considered of high and proven efficiency, resilient, and operationally quite reliable that generate an effluent of excellent quality (Sperling, 2005; Jordão and Pessoa, 2017). Thus, the treatment systems in operation provide greater assurance of effluent quality and, thus, greater feasibility of using reuse water.

Analyzing the quality of the treated effluent from the Alegria STP, Silva Jr. and Obraczka (2020) found that it can be used as mixing water for concrete plants without the need for post-treatment or polishing, because it already meets all the parameters established by relevant standards, such as NBR 15900 and even the specifications of international standards.

Besides water for concrete mixing, data collected by Faria (2020) show that treated effluents from the Alegria, Penha, Pavuna, and Sarapuí STPs meet most of the specifications for water quality parameters defined for uses in cooling towers and tumbling (bearing manufacturing). It is worth mentioning that even in the case of the need for investments in

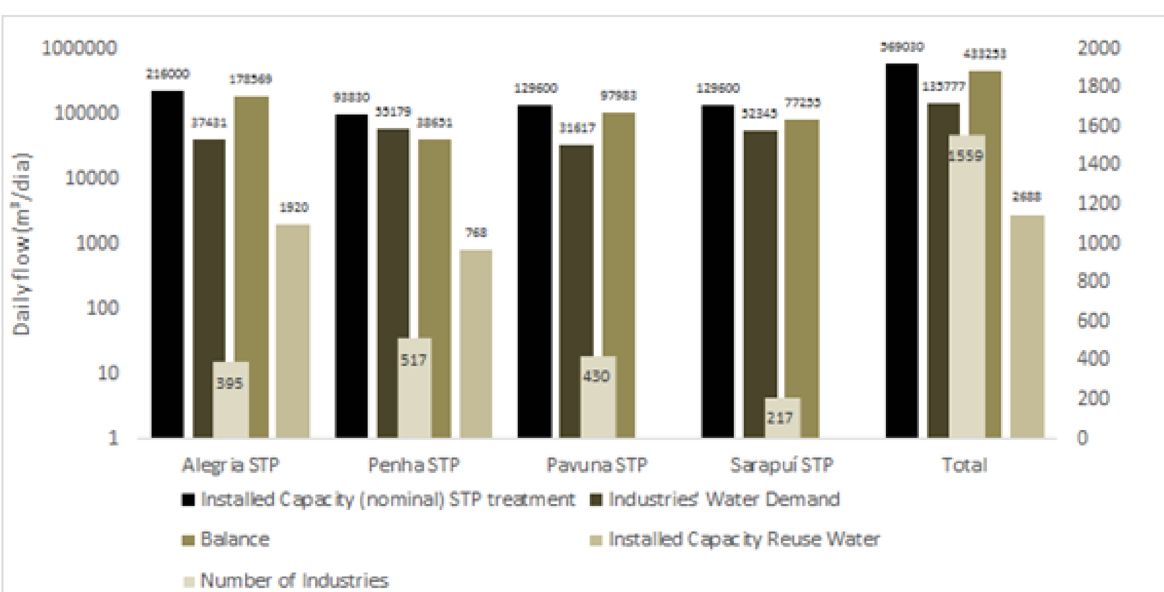

Figure 7. Production capacity of treated effluent of the STPs Alegria, Penha, Pavuna, Sarapuí and of reuse water of the STPs Alegria and Penha in relation to the industrial water demands of the companies listed in the survey, per STP

Source: The authors

an additional polishing stage, a good part of the treatment costs is already embedded in the process to minimally adapt the sewage to the requirements of DZ 215 R4 for disposal into water bodies, as recommended in the studies by Silva Jr. and Obraczka (2020), Faria *et al.* (2021).

Although many industries can be served by reuse water from more than one STP, it is important to highlight that almost all the listed companies are located less than 50 km from any of the four evaluated STPs, a distance considered as the maximum feasible radius for supply with reuse water by water truck (Campos, 2018, Obraczka *et al*., 2017).

4. CONCLUSION

Based on the further analysis of the georeferenced inventory of potential suppliers (STPs) and potential consumers of reuse water (processing industries) in the metropolitan region of Rio de Janeiro that has been developed since 2017, this article can demonstrate the potential for reuse of effluents treated for non-potable industrial purposes, respective to each of the four evaluated STPs (Alegria, Penha, Pavuna, and Sarapuí).

From a quantitative point of view, from their nominal installed treatment capacity, the four evaluated STPs can meet about four times the total potential industrial water demands for all the companies located in their respective radii of influence that were identified by the study. In reality, the installed capacity of the Alegria STP and those of Pavuna and Sarapuí could even meet respectively 100% and 95% of the total estimated flow of reuse water required by all 728 companies, while the Penha STP could meet about 70% of this demand. Even if only their treatment flows were counted instead of the nominal ones, the STPs could meet about twice the total demand of the listed industries.

Among the 728 industries identified as potential consumers, water demand is preponderant for the following sectors/types of industries: 14-*clothing*; 22-*rubber manufacturers*; *metal products manufacturers*; 19-*coke, petroleum products, and biofuels manufacturers*; and 20-*chemical products manufacturers*. The last two together represent 64% of the demand required in the study area. Typology 19-*Manufacturers of coke, petroleum products, and biofuels* stands out basically in the area of influence considered in the case of the Sarapuí STP, due to the estimated demands for REDUC (about 65415 m^3/day). The typology 30-*Manufacture of other transport equipment, except motor vehicles* also deserves to be highlighted, notably in the areas of influence of the Alegria and Penha STPs.

Due to the large estimated required flow for REDUC's companies, the Sarapuí STP presents as its strong point the higher ratio between available flow and number of industries and, as a negative point, its lower treatment flow, when compared to the largest STPs of the block (Alegria and Penha). On the other hand, the Pavuna STP is the one that presents the lowest performance among all the evaluated STPs: besides having the lowest available treatment flow and the lowest flow required by industries in its surroundings, it presents a low ratio between the required flow and the number of industries. The Penha STP, in turn, presents good indexes under several aspects: the 2nd highest treatment flow rate, the highest flow rate required by industries, besides the 2nd best ratio between flow rate and number of industries (second only to Sarapuí STP, due to REDUC's demand). Having the highest nominal installed capacity as well as the highest treatment flow rate among all the evaluated STPs, the Alegria STP, however, is only ahead of the Pavuna STP, both in terms of flow rate required by the industries within its radius of influence and in the ratio between flow rate and the number of these industries. Because it already has an RWPS that operated for years supplying reuse water to contractors, as well as its proximity to clusters of companies such as the CBPs in Caju and to major roads (Av. Brasil, Linha Vermelha), it can also be considered as having high potential for implementation of reuse.

In general, considering on one hand the concentration of large flows and the nominal capacities installed in the four wastewater treatment plants, and on the other, the operational reliability and good quality of the effluents from their secondary treatment systems, it is possible to infer that there is a great potential for the use of reuse water from these systems. It is worth noting that this practice (reuse) is more feasible the closer the respective suppliers (STPs) and consumers (industries) are to each other, mainly if water truck supply is used. Yet, for large demand and supply flows for a cluster or industrial complex, the alternative of supplying with a regenerated water pipeline should also be evaluated, along the lines of the system used by the AQUAPOLO project in São Paulo.

Through the survey and verification of the high number of grants for the use of water resources in the study area, it is possible to identify the existence of market niches made up of firms that are not served by the conventional potable system, but whose demands could be supplied by reuse water, generating new revenue opportunities for the utilities.

Due to the lack of more specific data, the flow rates of potential consumers (firms) were estimated based on allocation data and ANA indexes, also not being possible to differentiate the various types that make up these demands (production/beneficiation water, water for steam generation or cooling systems, water for washing equipment and floors, and others) and which may be common to industries in different sectors and typologies.

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The inventory and the data generated by this research can be used as a model and support for the survey of alternative water sources by various industrial sectors as well as for planning and management of water resources and sanitation in the metropolitan region of Rio de Janeiro. It is also configured as a decision support tool and for the implementation of the practice of wastewater reuse, which in turn is characterized as an alternative and strategic source of water supply for non-potable and industrial use, especially in the scenario of scarcity and criticality of water experienced by the metropolitan region of Rio de Janeiro.

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Received: May 2, 2021

Approved: July 5, 2021

DOI: 10.20985/1980-5160.2021.v16n2.1727

How to cite: Obraczka, M., Faria, A.M., Silva Jr, L.C.S., Ohnuma Jr, A.A., Oliveira, K., Muricy, B.C. (2021). Quantitative evaluation of the potential for industrial reuse from the effluents of four sewage treatment plants in the Metropolitan Region of Rio de Janeiro, Brazil. Revista S&G 16, 2. https://revistasg.emnuvens.com.br/sg/article/view/1727