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WASTEWATER REUSE OF SECONDARY TREATMENT AS AN ALTERNATIVE SOURCE OF WATER SUPPLY IN THE CITY OF RIO DE JANEIRO

Marcelo Obraczka
obraczka.uerj@gmail.com
State University of Rio de Janeiro – UERJ, Rio de Janeiro, Rio de Janeiro, Brazil

Douglas do Rosário Silva
douglas.rosario@outlook.com
State University of Rio de Janeiro – UERJ, Rio de Janeiro, Rio de Janeiro, Brazil

Adriana de Souza Campos
adrianamscampos@gmail.com
State University of Rio de Janeiro – UERJ, Rio de Janeiro, Rio de Janeiro, Brazil

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

ABSTRACT

Wastewater reuse is a common practice in many countries as a strategic alternative for supply. In Brazil, it has been growing in the corporate sector, although in public systems it is still incipient. Reuse can reduce pressures on springs/supply systems, delaying the need for expansion, and increasing water security. Seeking to generate knowledge and implement reuse, this work evaluates the potential for reuse in Wastewater Treatment Plant (WWTP) in the city of Rio de Janeiro, RJ. A survey of references, legislation and information was conducted, building a database on reuse and an unprecedented georeferenced mapping of generators and potential consumers of regenerated waters. Because of the large distances for rural employment and the high costs of conventional water for large consumers, it is clear that reuse is more viable for less noble and non-potable urban/industrial uses. Strategically located, the WWTPs, such as Alegria and Deodoro, generate large flows of good quality effluents that can be used for washing, equipment cleaning, track wetting and network clearing, even without further polishing. The research identified barriers to the implementation of reuse, such as the lack of technical knowledge, specific legislation and culture of reuse. As restrictions to the development of the study, the difficulty of obtaining data on the availability, demands and quality of effluent/regenerated waters was highlighted.

Keywords: Water shortage; Water resources management; Reuse of domestic effluents.

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1. INTRODUCTION

Although unknown to most of the population, reuse already occurs indirectly "in fact" in situations where the sewage of a city upstream of a watershed is discharged into a water body, used as a spring by another municipality further downstream (Bila et al., 2017).

Despite being a consolidated practice and strategic alternative for water supply in many countries, and already part of water resources management systems, reuse in Brazil is still in its infancy, except for particular cases in the corporate sector (Obraczka et al., 2017).

Aiming at strengthening and improving the management of water resources, the general objective of this study is to generate greater scientific and technical knowledge about reuse, providing support for its implementation as an alternative water supply in the city of Rio de Janeiro, RJ.

The research aims at the following specific objectives: 1) survey/compile legislation, standardization, specifications and case study data on reuse; 2) identify effective and potential generators and consumers of regenerated water in the city of RJ; 3) assess the suitability of the treated effluents of the effluent treatment plants (WWTP) for reuse purposes; 4) identify and evaluate potentialities and critical paths for the implementation of reuse in the city of Rio de Janeiro, RJ, especially for non-potable purposes; and 5) make suggestions for this implementation.

Based on data provided by the sanitation concessionaires and the environmental management system, the survey conducted an inventory of potential/effective regenerated water generators, including flow surveys and the quality of the larger sewage effluents that already operate reuse systems in the city of Rio de Janeiro, RJ.

As consumers, certain demands from the corporate sector were prioritized, based on data provided by the Federation of Industries of the State of Rio de Janeiro (Firjan) and through field research and the internet, using tools such as Google Maps. These data were compared with parameter values and limits recommended by studies, norms and legal frameworks regarding reuse water in Brazil and abroad.

Based on the data/results of the research, bottlenecks and potentials for reuse were identified in the city of Rio de Janeiro, RJ, consolidating propositions for its implementation.

2. LITERATURE REVISION

Water scarcity is increasing in large urban and industrialized centers, endangering regional and country development goals. Water is a fundamental input for industry; the prospect of its scarcity inhibits growth and removes the possibility of attracting new investments to the state of Rio de Janeiro that may bring more jobs and income (Firjan, 2015b).

Reuse is not a water source alternative in the country's water management and supply matrix, despite the serious problems related to water unavailability and/or the inability of conventional systems to meet growing demand (Obraczka *et al.*, 2017). In addition to reducing pressure on water supplies, reuse can contribute to improved water body quality (Silva Jr., 2017).

In many other countries, "regenerated" waters have been used for decades, playing an important socio-environmental and economic role (Bila *et al.*, 2017). Encouraged by the crisis and water scarcity, there are many consolidated cases of wastewater reuse, including for potable purposes, having a strategic role in the supply matrix of these countries (Campos, 2018).

Operating since the early 1990s in California, the Edward Little Water Recycling Unit is the largest water/wastewater recycling facility in the US, producing 1.75m3/s to meet five demand typologies, including industrial, potable and non-potable uses, and irrigation (Pieroni, 2016).

In Israel, 80% of water intended for agriculture comes from reuse systems (Jordan and Santos, 2015). In Brazil, where irrigation is equivalent to 2/3 of the demand for water and there are regions where needs already exceed water availability (ANA, 2017), a solution to overcome such deficits would be to use water that has received sewage, treated or diluted, in agriculture (Nuvolari, 2011).

However, the greatest advances in reuse occur for industrial and commercial purposes through private enterprise (Balassiano, 2018; SUBTIL *et al.*, 2017). Coupled with management practices to increase efficiency and reduce waste, reuse has been increasingly incorporated by the corporate sector. Especially since the last decade, reuse has become more economically attractive due to rising tariffs and the possibility of fines for excessive water use. In addition to reducing expenses, industries aim to reduce their dependence on public water systems (CNI, 2016). There are several consolidated experiences in large companies, such as Cetrel, Petrobras, Fiat Chrysler and Santista, using reused waters to replace their conventional sources of supply (Lima, 2018). Industrial areas are more attractive and viable to reuse, concentrating large amount of potential consumers (Bila *et al.,* 2017). In addition to large consumers, they pay a high value for water from the conventional system, being less demanding regarding the quality of water regenerated for non-noble uses (Araújo *et al.*, 2017; Campos, 2018). For the use in floor/equipment washing, it is required a quality much lower than those for more noble purposes, such as direct and indirect potable use, primary contact and industrial process input (Pieroni, 2016).

On the other hand, from public water/sewage treatment systems, only specific reuse initiatives can be identified, basically in the Southeast region. The most relevant is the Aquapolo project (São Paulo, SP), a public-private partnership between BRK Ambiental and São Paulo State Basic Sanitation Company (*Companhia de Saneamento Básico do Estado de São Paulo* – Sabesp) (Silva Jr., 2017). The regenerated waters of WWTP ABC (Sabesp) supply the ABC Paulista Petrochemical Complex, mainly used in cooling towers and boilers. The reuse system uses ultra-filtration membranes and reverse osmosis, and is the largest industrial water provider in South America, with a flow rate of 650 L/s (Rubim, 2012). According to Machado (2019), there is already identified demand by SABESP for 1200 L / s of reused water, which represents about 2% of the São Paulo Metropolitan Region water matrix, emphasizing that the installed capacity of sewage treatment is only 40% of this same matrix.

Also in the city of Rio de Janeiro, RJ, there is a greater vocation for the industrial/urban use of regenerated waters, both due to the greater proximity between generators and potential consumers, as well as the large flows demanded (Bila *et al.*, 2017).

However, the 17 WWTPs around Guanabara Bay return approximately 10.5 m^3/s of treated water/effluent to the sea, which could be supplied to the Rio de Janeiro industries (Firjan, 2015b). Only Alegria WWTP could generate 2.5m^3/s for reuse, almost four times what is reused through Aquapolo (Firjan, 2015b). However, even larger WWTPs that have regenerated water production systems (Alegria, Penha and Deodoro) make available an insignificant portion of their treated effluents for reuse (Zahner Filho, 2014).

Table 1 presents a compilation of data regarding examples of reuse in the country.

Outside the corporate universe, reuse flow rates represent an insignificant portion of the WWTP treatment flow rates. Of the total regenerated water produced in 2014 at Capivari II WWTP (5800m^3/day), only 40m^3/day (0.7%) was actually sold (SANASA, 2015).

In the municipality of Rio de Janeiro, in fact, current production is well below the installed reuse water generation capacity of the Penha e Alegria WWTPs (CEDAE, s/d). If only marketed flows are accounted for, this representativeness is even more limited. At Penha WWTP, the reused water used by the Municipal Urban Cleaning Company (COMLURB) is not billed by the Rio de Janeiro State Water and Sewerage Company (*Companhia Estadual de Águas e Esgotos do Rio de Janeiro* – CEDAE). However, reuse can be economically very advantageous for urban purposes, irrigation and other non-potable destinations, even using tank trucks up to 110 km in the case of Rio de Janeiro (Araújo *et al.*, 2017).

The economic viability of reuse by tanker trucks can occur within a radius of up to 50 km from the Alegria WWTP, depending on the volume demanded, generator/consumer distance, conventional system water tariffs and reuse water price (Campos, 2018).

The cost of m^3 of reuse water for collective washing is R$ 2.65/m^3 (FETRANSPOR, s/d). Farias (2019) and Branco (2016) indicate even lower costs of R$ 0.25/m^3 and R$ 0.6/m^3, respectively. The cost of m^3 of conventional water for large consumers of the industrial category is R$ 26.17 in the city of Rio de Janeiro. Even for the smallest residential consumption range (minimum), the average cost of m^3 of drinking water, considering the five largest utilities in the Southeast region, is R$ 2.60 (Campos, 2018).

Keeping an eye on this potential, Firjan (2015b) has been undertaking several initiatives to publicize/promote the reuse of WWTP effluents to meet the demands of industries in the city of Rio de Janeiro, also with the aim of combating economic stagnation in regions of the state.

For large flows and/or distances, however, road transport may be unfeasible, both due to the reduced flow capacity and the logistics available at the WWTP. In the case of Alegria WWTP, to expand reuse, it is necessary to expand the area for parking/loading trucks and implement a reserve unit (Campos, 2018).

Based on the use of exclusive water mains for regenerated waters, feasibility studies were carried out by CEDAE to meet the industrial water demands of the Rio de Janeiro Petrochemical Complex (COMPERJ) with treated effluent from Alegria WWTP (Zahner Filho, 2014). There have also been studies to supply Duque de Caxias Refinery (Reduc) with washing water from Guandu WWTP filters (CEDAE, 2006; Vieira Neto and Oliveira, 2008). However, these projects were never implemented.

Despite the various positive aspects listed and the high risks of water scarcity, there are no public policies and/or incentives for the implementation of reuse as an alternative source of water in the city of Rio de Janeiro (Campos, 2018).

The specific legislation on reuse itself is still incipient, notably at the federal level (Jordão and Santos, 2015;

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Table 1. Public and private effluent reuse in Brazil

Company	Typology	WWTP	Location	WWTP flow rate (l/s)	Reuse water flow (l/s)	Reuse %	Destination
Public system / concession - RJ							
CEDAE	Public	Alegria	Rio de Janeiro, RJ	1,529.1	2.1	0.14	Porto Maravilha works
CEDAE	Public	Penha	Rio de Janeiro, RJ	764.6	8.3	1.09	network cleaning, track, WWTP equipment
West Zone More Sanitation	private concessionaire	Deodoro	Rio de Janeiro, RJ	800.0	2.8	0.35	network cleaning, pathways
PROLAGOS	private concessionaire	Búzios	Búzios, RJ	250.0	0.8	0.32	golf course irrigation
Total flows treated and reused (public and RJ concession) (l/s)				3.343,7	14,0	0,42	
Percentage of Reuse in relation to the total flow treated, in average (%)					0,4		
Public system / concession - SP							
SABESP	Public	Barueri	São Paulo (SP)	10,042.2	3.0	0.03	
SABESP	Public	Parque Novo Mundo	São Paulo (SP)	2,613.0	60.0	2.30	
SABESP	Public	São Miguel	São Paulo (SP)	947.0	12.0	1.27	
SABESP	Public	Jesus Neto	São Paulo (SP)	250.0	35.0	14.00	
SANASA	Public	Capivari II	Campinas (SP)	72.6	28.9	39.81	
Total flow treated and reuse (public and SP concession) (l/s)				13,924.8	138.9	1.00	
Percentage of Reuse in relation to the total flow treated, in average (%)					1,0		
Public Private Partnership for Industrial Use							
AQUAPOLO/SABESP	PPP	ABC	São Paulo (SP)	2350.0	650	27.66	industrial use (boilers, cooling towers)
Total flow treated and for reuse (PPP) (l/s)				2350.0	650	27.66	
Reuse Percentage in relation to the total flow treated (%)					27.7		
Private / corporate systems for industrial use							
CETREL	Private		Camaçari, BA	972	200	20.58	
RAIZEN	Private						
SANTISTA	Private						
FIAT/CHRYSLER	Private						
ALCOA	Private			34.7	3.1	9.00	
PETROBRAS	Private	several		6893.4	792.7	11.50	various industrial plants
COCACOLA/AMBEV	Private						
Total flows treated and for reuse (corporate for industrial use) (l/s)				7900.1	995.8	12.61	
Percentage of Reuse in relation to the total flow treated, in average (%)					12.6		
Private agricultural system							
ACTIONSHOP	Private		C. Macacu, RJ	7.6	variable	1.5	Fertigation, lemon and guava crops
Treated and reused subtotals (private for agricultural use) (l/s)				7.6	variable	1.5	
Reuse percentage in relation to total treated flow (%)					variable	20(1)	
All systems evaluated/surveyed							
Total flows treated and for reuse for all surveyed typologies (l/s)				27526.2	1798.7	6.53	
Percentage of Reuse in relation to the total flow treated, in average (%)					6.5		

Source: Authors

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Obraczka *et al.*, 2017). Only recently have some important legal frameworks, such as Law 9433/97, been updated, incorporating reuse, albeit in a generic way (Silva Jr., 2017).

In addition to the lack of greater legal support, the small advances are due to the lack of greater knowledge on the part of public and private technicians/managers and society itself, coupled with the lack of a "culture of reuse" at national level (Bila et al., 2017).

However, reuse should always be contemplated in the planning of cities and watersheds, establishing policies that encourage the practice with mechanisms such as tax exemption/reduction and tariff restructuring. At the same time, investments in research, transparency, dissemination of results are necessary tools to increase acceptance, reduce costs, and provide the proper use and operation of reuse systems (SANASA, 2017).

3. SCIENTIFIC METHODOLOGY

The methodological script was divided into four steps:

In **Step 1**, bibliographic references and data were collected from various available sources of information. A survey of reuse-related legislation in Brazil has also been conducted in recent decades. Legislation, standards and specifications were searched on the international scene, including countries considered as reference by example of the USA, Australia and members of the European Union (EU).

In Step 2 a general characterization/inventory of effective and potential generators and consumers of reused waters in the city of Rio de Janeiro was made. The data were obtained from companies and competent entities, including: environmental and sanitation/water resources management bodies, corporate associations and business entities. The database has been expanded from information available on web pages and websites.

Regarding the effective (and potential) reused water generators, besides data from 29 WWTPs located in the municipality, information was added on two other potential sources of regenerated water: the reservoirs of the flood damping system in the region of Tijuca / Praça da Bandeira and the River Treatment Units (RTU).

As potential consumers, priority was given to those industries and enterprises that require the highest water flows. In the absence of more specific data on water supply/demand, only industries with over 500 employees were considered, based on Firjan's Rio de Janeiro State Industrial Registry (2015b).

Specific demands for public use were also included, such as street washing, fairs and monuments, irrigation of parks and gardens, which "a priori" do not require high quality water. In the same vein, projects such as train garages, buses and trucks for urban cleaning services, terminals, ports and airports were also registered. Data regarding bus garages were collected from the Rio de Janeiro State Federation of Passenger Transport Companies (*Federação das Empresas de Transportes de Passageiros do Estado do Rio de Janeiro* – FETRANSPOR).

From the address/location of generators and consumers, the data was converted to coordinates using Google Maps. Company data and their geographic coordinates were organized in Excel spreadsheets, allowing their importation into the QGIS program.

Based on this software, a base/mapping was generated containing basic information, such as typology, location, flow, distance and quality of effluents (generators) and/or regarding the quality required to meet the demand (consumers). In specific layers of this cartographic base, other relevant information was inserted, such as main water bodies, geopolitical and planning boundaries, as well as watersheds and sewage.

Then, the availability of regenerated water was analyzed, evaluating aspects that justify and/or make possible the implementation of a reuse system, such as the distance between its potential consumers and generators.

In order to provide a better basis for the research regarding effluent quality and potential reuse, in **Step 3**, the results of periodic analysis of control/monitoring of WWTP effluents located in the city of Rio de Janeiro were surveyed/evaluated. Having secondary treatment, they were considered/adopted as the most viable generators for reuse implementation because they concentrate large sewage flows and maintain the good quality of available effluents in strategically located places in the municipality.

Due to the greater availability of quality data, emphasis was placed on the WWTPs in planning area 5 (AP-5). For this characterization, the control/monitoring parameters were used and are available in: a) Pollutant Load Declarations (Load, Flow, Biochemical Oxygen Demand - BOD, Chemical Oxygen Demand - COD and Total Non-Filterable Residues - TNFR), referring to the years 2014 and 2015; b) Effluent Assessment Reports (*Relatórios de Avaliação de Efluentes* – RAE) (parameters COD, BOD, TNFR, turbidity, oils and greases, active substances in methylene blue - MBAS, sedimentable materials and pH), from 07/2015 to 06/2016; and c) Results of analyzes carried out for follow up/monitoring of 18 WWTPs.

The collection/analysis campaigns were conducted in 2016, analyzing seven quality parameters of these effluents (BOD, TNFR, pH, sedimentable residues, oils and greases, MBAS/surfactants).

Then, the average values of the results of these parameters were compared with limits established and/or recommended by the legislation/standardization referring to reuse waters in Brazil, based on two municipal laws of the state of São Paulo (Campinas and São Paulo), besides two others abroad (USA and Australia), countries considered as reference in the theme. For this, three specific indices (BOD, TNFR/total suspended solids - TSS and pH) were adopted, as they are the only common/available parameters in the data sources used.

In view of the lack of empirical data to characterize the reuse waters in the WWTP in the city of Rio de Janeiro, the data available in studies/works of the bibliography consulted, notably that of Ramos *et al.* (2005) was also included in this comparison. These data refer to the Penha WWTP regenerated waters, based on 16 samples/analyzes performed in January 2013, for the parameters pH, turbidity, BOD, COD, TNFR, residual chlorine and thermotolerant coliforms. In addition, the data for 2005 and 2008 were listed, as well as data on reuse waters of the Alegria WWTP (Ramos *et al.,* 2005; Vieira Neto and Oliveira, 2008).

By way of illustration as to their potentiality for industrial use, this data from the Penha and Alegria WWTPs was also compared with some limits raised in references (Pieroni, 2016; Giordano (s/d); Ramos et al., 2005; Vieira Neto and Oliveira, 2008) for use in cooling towers (chloride parameters, dissolved and suspended solids, hardness, alkalinity, pH, COD, BOD, temperature, turbidity, coliforms, and residual chlorine).

In **Step 4** a general evaluation of the results of the previous steps was made, identifying potentialities and obstacles to the implementation of reuse. Suggestions were also made for better use of this alternative source of water, with emphasis on industrial and non-potable purposes in the municipality.

4. RESULTS ANALYSIS

Next, the main results are presented and analyzed by step of the adopted methodological script.

Step 1: Survey and compilation of legislation and standardization in Brazil and abroad.

From the data obtained by the proposed survey, it was possible to evaluate the evolution of the Brazilian legislation regarding reuse, identifying legal frameworks established in Brazil in the last two decades, aiming at its regulation.

The available legislation is very diverse in the different states of the federation, and the Southeast is the most advanced in this regard.

The scarce legislation available focuses primarily on non-potable urban and agricultural uses (Obraczka *et al.*, 2017).

For the most part, the legal framework is made up of laws with more general characteristics, with reuse accompanying other themes that are the real focus of normatization. Reuse is not specifically regulated, especially for uses considered to be nobler, such as desedentation, aquifer recharge and other more stringent destinations for the required quality. This is the case of NBR 13969/1997, which prioritizes the aspect of complementary treatment and final disposal of liquid effluents, although it is considered as an important milestone towards the regulation of reuse in Brazil, when establishing classes of use and parameters to be met (Silva Jr., 2017).

On the other hand, in the last years of the 2000s, it is already possible to identify the emergence of more detailed legislation, especially of local nature, as in Campinas and São Paulo (Campos, 2018). It is believed that this advance in relation to the other federative entities, even defining some parameters and specific classes of use for regenerated waters, is due to the demands of local reuse projects, in this case the Aquapolo (SP) and the Capivari II WWTP (Campinas), considered as the most relevant reuse systems from domestic sewage operating in the country (Pieroni, 2016).

It is worth mentioning the most recent initiatives in the federal sphere, seeking to recognize the relevance of reuse in the current scenario, inserting it, although more generally, in one of the most important legal frameworks, the Water Resources Law/Policy (9433/97). Since 2015, an amendment project was underway to include the use of lower quality water in less demanding uses. Even after being approved by the National Congress of the Environment and Sustainable Development and the Constitution and Justice and Citizenship Committees, in 2019 it was filed (House of Representatives, 2019).

On the other hand, many other countries have extensive and detailed legislation regulating the different possible uses/destinations for treated effluent, setting specific parameters depending on the intended destination of the regenerated water (Obraczka *et al.*, 2017; Bila *et al.*, 2017).

Developed by California in the early twentieth century (1918), the first US water reuse regulation deals with sewage use in agricultural areas (Jordan and Pessoa, 2014). There is currently a valid regulation throughout the United States, the USEPA - Guidelines for Water Reuse. However, some states have their own regulations, such as California. Considered to be one of the most advanced sites for wastewater reuse, its Water Recycling Criteria legislation has even more restrictive parameters than the federal one for certain uses of regenerated water.

EU member states' regulations follow the directives drawn up by their executive body, the European Commission (Klemes, 2012). Some member countries have their own legislation regulating reuse, such as France, Greece, Italy, Portugal, Spain and Cyprus, many of which are based on World Health Organization (WHO) guidelines. In its latest version (2006), the WHO "Guidelines for the Safe Use of Wastewater, Excreta and Gray Water in Agriculture" already contain regenerated microbiological and chemical parameters for water.

The EU is developing joint legislation. In February 2019, the European Parliament adopted rules to facilitate water reuse in agricultural irrigation and to help manage water scarcity and droughts to be negotiated with the EU Council, where national governments are represented, to reach an agreement on the final regulation. The proposal establishes minimum requirements for the reuse of treated wastewater and to ensure an alternative and reliable water supply, especially regarding water quality and monitoring. It includes rules on the roles and responsibilities of the various operators involved, and the main risk management activities (European Parliament, 2019).

In 2006, Australia developed and consolidated a comprehensive reuse water legislation / standard, the Australian Guidelines for Water Recycling (AGWR) (Australian Government Initiative, 2006).

Table 2 provides a compilation of the various allowable/possible uses for reuse water under current legislation in US states, EU member countries, and Australia (Oceania).

Table 2. Supported destinations for water reuse abroad

Country / State		Expected destination for reuse water
United States	Arizona	Irrigation, industrial processes, aquifer recharge and small uses in urban lakes, fountains and marshland restoration.
	Nevada	Irrigation of golf courses, use in parks and recreation, aquifer recharge.
	Colorado	Evaporative and non-evaporative industrial processes, road maintenance and construction, landscape irrigation, use in zoos, agricultural irrigation for inedible and forestry types, wash water, commercial laundries, vehicle wash, non-residential fire protection.
	Califórnia	Irrigation, commercial and industrial use (cooling), geothermal energy, seawater intrusion barrier, aquifer recharge, restoration of natural systems. Direct and indirect potentiation
	Washington, Oregon and Idaho	Irrigation, cooling in electricity production, street cleaning, aquifer recharge, commercial and industrial processes, restoration of marshy areas.
	Flórida	Irrigation of residential areas, golf courses, parks and agriculture (with restrictions), industrial cooling, wetland reclamation and aquifer recharge.
União Europeia	France	Irrigation of flower beds, golf courses, cereals and gardens. Industrial cooling.
	Germany	Agriculture
	Greece	Supply of regions with problems of scarcity and agriculture.
	Italy	Agriculture and industrial use
	Portugal	Irrigation, road construction and vehicle washing.
	United Kingdom	Irrigation, vehicle wash, industrial cooling.
	Spain	Industrial use. Supply of regions with problems of scarcity and agriculture.
Oceania	Australia	Irrigation of gardens, landscape, food crops and sports fields. Application of non-potable water for reuse in municipal environments where access is controlled or restricted by barriers. Flush toilets and washing machine.

Source: Obraczka *et al.* (2017).

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Step 2: General characterization/inventory of actual and potential generators and consumers of reused waters in the city of Rio de Janeiro

Adopted as a case study, the municipality of Rio de Janeiro covers an area of 1,200,177 km² and about 160 neighborhoods (Sebrae, 2015). Its population in 2018 was estimated at 6,688,927 inhabitants, representing a demographic density of 5,265.82 inhab./km². It is the second largest gross domestic product (GDP) in the country and the first in the state of Rio de Janeiro (IBGE, 2018).

Sanitation of most of the municipality (AP1, AP2, AP3 and AP4) is under the responsibility of CEDAE, while that of AP5 (West Zone) was granted to the private initiative in 2012 (Obraczka and Leal, 2016).

There are dozens of WWTPs in operation in these five PAs, with a wide spectrum of tributary flows: from just 1.0 L/s (Minha Casa Minha Vida Program WWTP) to about 1500 L/s, in Alegria, Caju, largest currently in operation (Obraczka *et al.*, 2017). In addition to the Alegria WWTP, there are larger ones operated by CEDAE, which were built from the Guanabara Bay Decontamination Program, initiated in the 1980s: the Pavuna-Meriti (1500 L/s) and Sarapuí (1500 L/s). There is also Penha WWTP (800 L/s), the oldest of all, opened in 1940 (Bielschowsky, 2014; CEDAE, 2006; Zahner Filho, 2014).

In AP5 the largest WWTPs are Deodoro (expanded to 750 L/s), Sepetiba (70 L/s), Pedra de Guaratiba (40 L/s) and Vila Kennedy (40 L/s) (Bielschowsky, 2014; Silva JR., 2017; Pieroni, 2016; ANA, 2017; Obraczka *et al.*, 2017; Torres, 2018). With a treatment capacity of 250 L/s, Santa Cruz WWTP is not yet operational (Pieroni, 2016).

According to Torres (2018) and ANA (2017), the vast majority of these WWTPs operate with capacity well below their installed capacity, as detailed below in Table 6, highlighting that the values of these flows vary, depending on the source consulted.

Based on the information obtained from the concessionaires, it can be seen that, of the 26 operating WWTPs raised in the city of Rio de Janeiro, only three generate water for reuse. In the Penha and Alegria WWTPs, in addition to the conventional secondary treatment system, there is a polishing stage for reuse, consisting of direct in-line filtration, followed by chlorine disinfection, without reservoirs. Regenerated waters are used primarily for less noble and non-potable destinations.

The reuse initiatives are punctual and basically occur as a result of direct negotiation between the generator and the consumer, as in the case of CEDAE and contractors, using regenerated water from Alegria WWTP for the works of the Porto Maravilha Project. However, as the pace of the works slowed and the contract was terminated, supply was interrupted (Obraczka *et al.*, 2017; Porto Novo Concessionaire, 2013). There is also the use of a small portion of the regenerated waters of the Penha WWTP for street washing, fairs and the like by COMLURB (Figure 1). In return, for a certain period, COMLURB received CEDAE WWTP sludge from its landfill (Pieroni, 2016; CEDAE, 2013).

At the Deodoro WWTP, the reused water comes from a pilot project with a capacity of 240m³/day and a 40m³ reservoir that has been operating since 2015, consisting of simple membrane pressure filtration followed by chlorination (Figure 2). Regenerated waters are used by the company itself only for non-potable and less noble purposes such as clearing nets, washing equipment, execution of networks by non-destructive methods and the reduction of particulate matter by wetting in the works of local works for net settlement (Grupo Águas do Brasil, 2015; Pieroni, 2016).

Figure 1. Public road washing with reused water in downtown RJ. Source: Porto Novo Concessionaire (2013).

Figure 2. Reuse water production system at Deodoro WWTP. Source: Obraczka *et al.* (2017).

From the information obtained, a georeferenced base/map (Figure 3) was prepared including generators (WWTP) and potential consumers listed (large enterprises/industrial areas).

This database is associated with a database with the main information about generation, such as flow and quality of effluent and WWTP (active and inactive) in the municipality of Rio de Janeiro by concession area, size and capacity of rainwater buffering reservoirs in Tijuca, and operational RTUs (Flamengo, Arroio Fundo, and São Conrado). In addition to estimated demand flows for large consumers, the bank includes general information on the study area, such as the identification and delimitation of municipal PAs, watersheds/sewage, and main water bodies.

As for two of the three potential sources of reuse water originally listed by the research – damming reservoirs and RTU – in practice, they do not prove to be viable alternatives.

According to Rio-Águas technicians, the accumulated rainwater in the reservoirs needs to be sent as soon as possible to the surrounding water bodies, providing their damping capacities so they can act properly in the next rain. Therefore, there is a limiting factor due to the restriction of the time for withdrawal aiming at its reuse. Moreover, the quality of these waters is greatly compromised by diffuse pollution, interconnections with sewage networks and the presence of all kinds of waste/garbage. Such negative characteristics considerably restrict their viability for reuse.

Regarding the RTUs, whose operation is outsourced to the private sector, these systems are inserted in the water body, not having storage capacity for possible reutilization/reuse. Regarding effluent quality, even after several attempts, it was not possible to obtain more information about its monitoring.

Due to the aspects listed above, the research focus was directed to the 3rd alternative of potential regenerated water sources considered: the largest WWTP operating in the city of Rio de Janeiro. In addition to large concentrated flow rates, these stations have effluents treated at the secondary level, which already have a good standard/quality, to meet the demands of efficiency and treatment required by environmental legislation. Table 3 presents a compilation of data collected on larger WWTPs in the city of Rio de Janeiro with secondary treatment and/or with reuse.

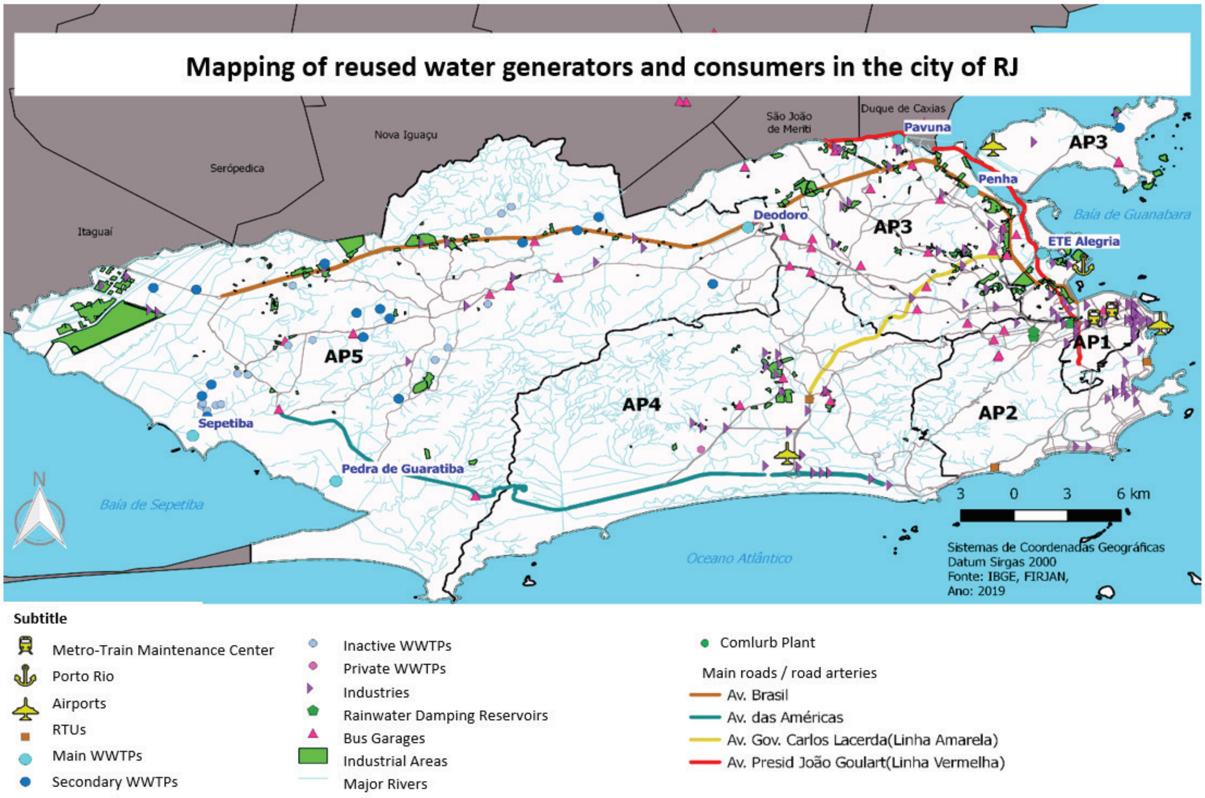


Figure 3. Mapping of reused water generators and consumers in the city of RJ

Although three of the WWTPs have great potential for reuse, already operating their own systems (WWTP Penha since 2007, and WWTP Alegria and WWTP Deodoro since 2015), in practice this occurs on a very small scale, with flow rates that can be considered very small when compared with those of treated effluent.

In Alegria, this percentage is 0.14%, while in Penha WWTP is 0.23% or 1.1%, depending on the source of information adopted (Manhães and Araujo, 2015; Silva Jr., 2017). In 2007, at Penha WWTP, only approximately 6% of the reuse water production capacity of 720 m^3/day was reused for internal use (centrifuge and vehicle washing) and external use (COMLURB and others) (Vieira Neto and Oliveira, 2008). Considering the total treatment flow (800 L/s), the percentage reused in 2007 would be 0.16%, while the installed potential of the reuse system is equivalent to 1% of the total treated effluent.

At Penha WWTP between 2007 and 2012, the production of regenerated water ranged from 23,085 to 70,296m^3/year; it was only 1,080m^3/year at the beginning of its operation though. In 2014, the volume of treated effluent for the production of regenerated water averaged 0.2% of the total treated. (Zahner Filho, 2014).

In the case of Deodoro WWTP, considering the inflow with the system expansion in 2017 (about 750 L/s), the reuse water flow (2.8 L/s) represents a little less than 0.4% of total treated sewage flow.

Based on data from Obraczka et al. (2017) and Bila et al. (2017) and in the compilation presented here (Table 3), it appears that less than 1% of the effluent treated / generated effluent flow in the evaluated WWTP is reused as reused water.

Also, only about 1/3 of the installed reuse water production capacity is being used, used in less noble destinations, such as cleaning roads, washing yards and equipment and clearing nets and galleries, as well as for irrigation of parks, garden irrigation and washing of sports fields (CEDAE, 2013; Vieira Neto and Oliveira, 2008).

It is also worth mentioning that there are two larger WWTPs currently under construction and/or commissioning in Rio de Janeiro: Santa Cruz WWTP (PMRJ/ZOMS) and Alcântara WWTP (CEDAE). Similarly, there are dozens of smaller systems in operation in the municipality that do not reuse and there is no forecast for reuse of their treated effluents in the future. With a larger number of WWTP operating without reuse, this representativeness is actually even lower than the one calculated above.

From a commercial point of view, reuse is even less relevant: much of the regenerated water sent to consumers does not even generate direct financial return to utilities. This is the case of Penha WWTP's reuse water: a small flow is used by CEDAE to wash equipment/vehicles and the other is transferred to COMLURB, free of charge (Ramos *et al.*, 2005).

In the current scenario, reuse does not (yet) represent a source of revenue for the concessionaires, and the effluents treated in the WWTP are basically "waste" to be properly disposed of in the receiving bodies, in compliance with the relevant legislation.

It can be seen that the largest potential consumers of reused water are the industrial areas of Santa Cruz, Campo Grande and Itaguaí, located on AP5 and closest to the ZOMS concession area WWTPs, such as Deodoro, Pedra de Guaratiba, and Sepetiba.

In the case of the CEDAE WWTP, it can be seen that the clearest potentials are configured from the larger WWTPs (Alegria, Penha, Pavuna-Meriti, and Sarapuí), located in the most industrialized region (AP1 and 2 - Central and Northern Zones), where certain niches/opportunities for reuse water supply were identified, such as in the care of concrete plants and garages in Caju, from the Alegria WWTP.

Both CEDAE and ZOMS technicians report the occurrence of several demands for reuse water, notably for projects located near or around the WWTP; however, such requests are not met. This is the case of the demand for irrigation of the Brazilian Army's instruction/riding fields, with regenerated waters from Deodoro WWTP.

On the other hand, projects to meet the high demands of the private sector, such as those of Reduc and COMPERJ through exclusive reuse water mains, did not advance, bumping into obstacles such as the large distances between generators and consumers, requiring a much higher level of regenerated water quality (which would require greater investment in the current polishing system) and other bureaucratic and/or institutional impediments.

Based on the data collected, it is inferred that the practice of reuse from WWTP in the city of Rio de Janeiro is still very incipient, occurring in a restricted way in the three above-mentioned stations, using tanker trucks and without greater direct financial returns to the respective concessionaires.

An important data also raised by the research is the reduced tributary flow of raw sewage to the WWTPs, in re-

Table 3. Data from WWTP municipality of Rio de Janeiro

Generating Source (WWTP)	**Concessionaire responsible**	**Type of secondary treatment**	**Average flow (m^3/day)/(l/s)**		**Destination of reuse water / year of commencement of operation**
			Project	**Capture for reuse**	
			Operation	**In operation**	
Deodoro WWTP (RJ)	ZOMS (1)	Extended aeration activated sludge (3)	86400/1000(3)(4)	240/2.8	Network clearance, equipment and track washing / 2015
			18.144/230(3) 64800/750(4)	240/2.8	
Sepetiba WWTP (RJ)	ZOMS	Extended aeration activated sludge	5.184/70	There is no	-
			230/2.7(5)		
Pedra de Guaratiba WWTP (RJ)	ZOMS	UASB reactor + submerged aerated biofilter + secondary decanter	3,456/40	There is no	-
			2014/23.3(5)		
Vilar Carioca WWTP (RJ)	ZOMS	Activated sludge per batch	1,115/13	There is no	-
			1120/13(5)		
Vila Kennedy WWTP	ZOMS	Oxidation Valve	3370/39	There is no	-
			3361/39		
Nova Cidade WWTP	ZOMS	Activated sludge extended aeration	2800/32	There is no	-
			103/1.2(5)		
Santa Cruz WWTP (not yet operational)	PMRJ/ ZOMS	Secondary treatment	21600/250	There is no	-
			-		
Alegria WWTP (RJ)	CEDAE	Extended aeration activated sludge	216.000/2500	720/8.3	Obras do Porto Maravilha; sistema atualmente inoperante/2015
			132106/1529	181/2.1	
Penha WWTP (RJ)	CEDAE	Deep aeration activated sludge / Deep Shaft	103,680/1200	720/8.3	COMLURB; lavagem de veículos e equipamentos da ETE/2007
			66096/765	112/1.3	
Sarapuí WWTP (SJ de Meriti)	CEDAE	Chemically Assisted Primary + Activated Sludge	129,600/1500	Em projeto	-
			38880/450		
Pavuna- Meriti WWTP (RJ)	CEDAE	Chemically Assisted Primary + Activated Sludge	129.600/1500	Em projeto	-
			19080/220		
Ilha do Governador WWTP (RJ)	CEDAE	Extended aeration activated sludge	38.880/450	Não há	-
			31968/370		
Total Project Flow (A)			720085/8584	1680/19.4	-
Total Operating Flow (Effective) (B)			359758/4163	533/6.2	
% (A/B)			50		-
% Reuse Project / Effective Operating Flow			0.47 (2)		-
% Reuso Efetivo/Vazão Operacional Efetiva			0,15		-

Sources: Bielschowsky (2014); Silva Jr., 2017; Pieroni, 2016; ANA, 2017; Obraczka *et al.*, 2017; Torres, 2018

Notes: (1) ZOMS - West Zone Plus Sanitation. (2) Considering operating flows. (3) Flow rate prior to commissioning of the extension (Nereda System). (4) Flow after expansion (Nereda System). (5) 2014/2015 Pollution Cargo Declaration Data lation to their total installed treatment capacity: only 50%. It is noteworthy that such idleness is still a paradox, given the large amount of freshwater sewage being continuously poured into local water bodies, polluting important rivers and bays such as Guanabara and Sepetiba.

Step 3: Effluent quality for reuse

Based on data from three parameters (BOD, pH and TNFR) measured in 18 AP5 WWTP (Figures 4 and 5), compliance with the limits was assessed in the light of the relevant Australian and US legislation (restricted and industrial uses) (Figure 6).

Figures 4 and 5. Sampling and analysis of physical parameters at Coqueiros WWTP, Santíssimo, RJ.

It is found that most of the effluents from secondary treatment of the assessed WWTP would already meet several standards of the legislation adopted as reference, especially those of the United States Environmental Protection Agency (USEPA) for restricted use, without the need to add polishing steps and/or post-treatment for its suitability.

It is also noteworthy that the larger WWTP (Deodoro, Sepetiba, Guaratiba Stone, Nova Cidade, and Vilar Carioca) meet the limits for the three listed parameters; Only Vila Kennedy does not meet USEPA's BOD and TNFR standards (restricted and industrial uses).

Among the smaller WWTPs, the only cases of non-attendance are: São Fernando, Vila João Lopes and Ana Gonzaga (in the case of BOD) and Vila João Lopes, Coqueiros, and Ana Gonzaga (TNFR). Most of the results found for TNFR and pH also meet the limits established by AGWR, except for Vila J. Lopes, Vila Kennedy, Coqueiros, and Ana Gonzaga WWTPs (TNFR only). It is noteworthy that, except for Vila Kennedy, these are smaller WWTPs, which are not significant in the total amount of treated flows.

Comparing with the reuse standards available in Brazil, the average results found for the treated effluents from these WWTP would also meet, without polishing, the restrictions established by the Campinas Class B legislation (landscape irrigation, civil construction, clearing of galleries, and firefighting) and São Paulo (severely restricted use) BOD and maximum TNFR of 30 mg/L and pH from 6 to 9 (respectively, Joint Resolution SVDS/SMS 09/2014 and Resolution SES/SMA/SSRH-01 of June 28, 2017). On the other hand, the results found do not meet several necessary requirements / more restrictive parameters of international law for more noble uses of regenerated waters, such as the AGWR BOD. (<20 mg/L).

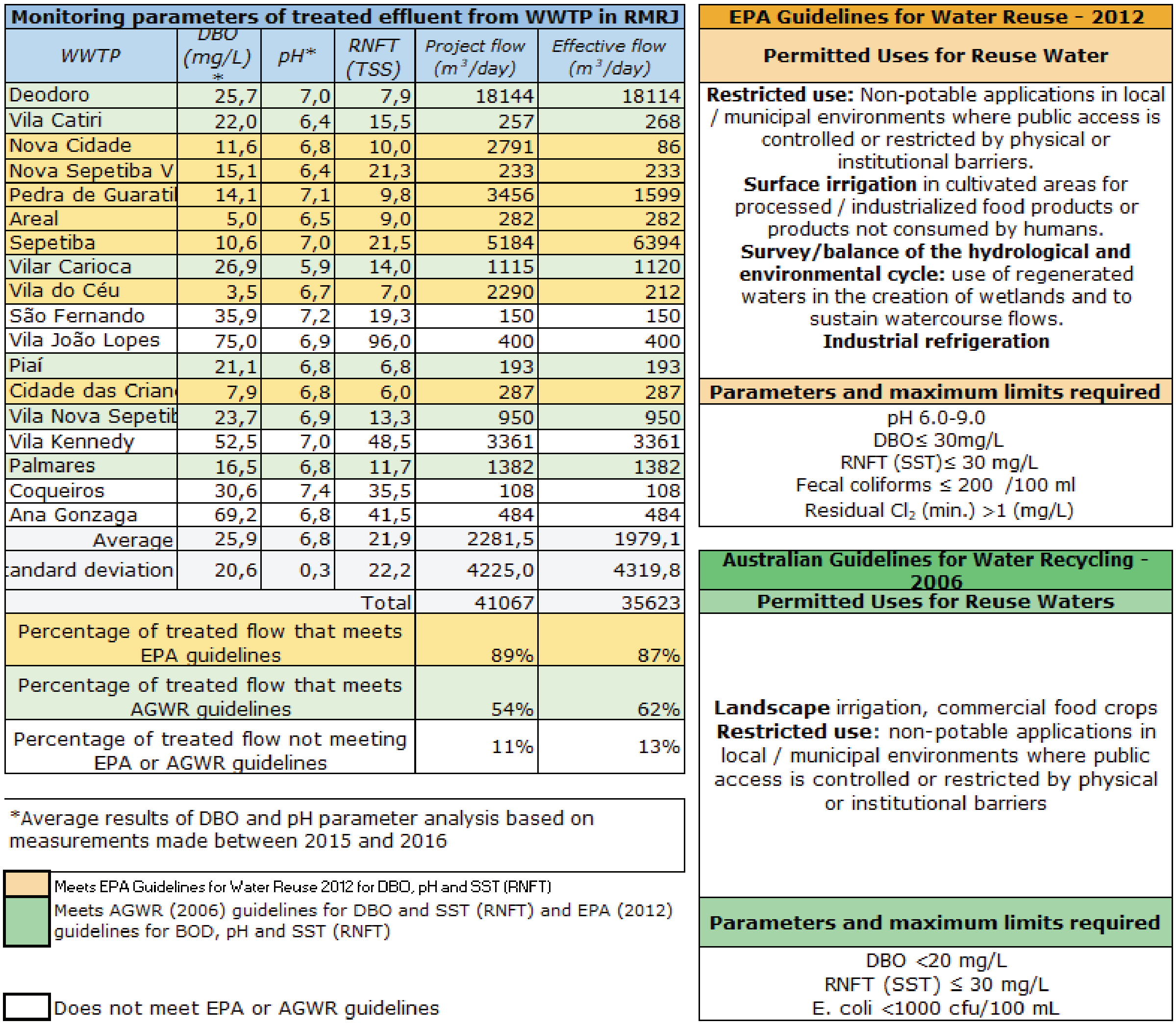
Table 4 lists some of these limits established by standards/legislation, as well as values recommended by references (PROSAB, 2006), comparing them with data from analysis / monitoring.

For BOD, TNFR and pH parameters the average, maximum and minimum values available for independent laboratory analysis are discriminated. For the other parameters (COD, Flow), the data from the RAE referring to the effluents treated from the WWTPs here evaluated are used. The weighted values take into account the average concentrations and flows in each WWTP.

Regarding the water quality parameters for reuse of WWTPs, no further data were obtained from the Concessionaires and/or the environmental control agencies. However, by way of comparison, data from Zahner Filho (2014) and Ramos et al. (2005) were selected for Penha WWTP, in addition to analyzes carried out in 2005 and 2008 (CEDAE, 2008). Data were also included for the reuse waters of Alegria WWTP.

Note that the results show a similar pattern across all sources, providing greater safety/reliability over these analyzes. On the other hand, the available data basically boils down to certain physicochemical and bacteriological parameters.

It can be seen that the BOD and TNFR parameters available for the Penha and Alegria WWTP reuse waters meet all limits and recommendations, including all NBR13969/77 Classes except Campinas (Class A) and São Paulo (moderate restriction) for TNFR. The only other two cases of



Monitoring parameters of treated effluent from WWTP in RMRJ					
WWTP	DBO (mg/L) *	pH*	RNFT (TSS)	Project flow (m³/day)	Effective flow (m³/day)
Deodoro	25,7	7,0	7,9	18144	18114
Vila Catiri	22,0	6,4	15,5	257	268
Nova Cidade	11,6	6,8	10,0	2791	86
Nova Sepetiba V	15,1	6,4	21,3	233	233
Pedra de Guaratil	14,1	7,1	9,8	3456	1599
Areal	5,0	6,5	9,0	282	282
Sepetiba	10,6	7,0	21,5	5184	6394
Vilar Carioca	26,9	5,9	14,0	1115	1120
Vila do Céu	3,5	6,7	7,0	2290	212
São Fernando	35,9	7,2	19,3	150	150
Vila João Lopes	75,0	6,9	96,0	400	400
Piaí	21,1	6,8	6,8	193	193
Cidade das Crian	7,9	6,8	6,0	287	287
Vila Nova Sepetib	23,7	6,9	13,3	950	950
Vila Kennedy	52,5	7,0	48,5	3361	3361
Palmares	16,5	6,8	11,7	1382	1382
Coqueiros	30,6	7,4	35,5	108	108
Ana Gonzaga	69,2	6,8	41,5	484	484
Average	25,9	6,8	21,9	2281,5	1979,1
tandard deviation	20,6	0,3	22,2	4225,0	4319,8
Total				41067	35623
Percentage of treated flow that meets EPA guidelines				89%	87%
Percentage of treated flow that meets AGWR guidelines				54%	62%
Percentage of treated flow not meeting EPA or AGWR guidelines				11%	13%

*Average results of DBO and pH parameter analysis based on measurements made between 2015 and 2016

🟧 Meets EPA Guidelines for Water Reuse 2012 for DBO, pH and SST (RNFT)

🟩 Meets AGWR (2006) guidelines for DBO and SST (RNFT) and EPA (2012) guidelines for BOD, pH and SST (RNFT)

☐ Does not meet EPA or AGWR guidelines

EPA Guidelines for Water Reuse - 2012

Permitted Uses for Reuse Water

Restricted use: Non-potable applications in local / municipal environments where public access is controlled or restricted by physical or institutional barriers.
Surface irrigation in cultivated areas for processed / industrialized food products or products not consumed by humans.
Survey/balance of the hydrological and environmental cycle: use of regenerated waters in the creation of wetlands and to sustain watercourse flows.
Industrial refrigeration

Parameters and maximum limits required

pH 6.0-9.0
DBO≤ 30mg/L
RNFT (SST)≤ 30 mg/L
Fecal coliforms ≤ 200 /100 ml
Residual Cl_2 (min.) >1 (mg/L)

Australian Guidelines for Water Recycling - 2006

Permitted Uses for Reuse Waters

Landscape irrigation, commercial food crops
Restricted use: non-potable applications in local / municipal environments where public access is controlled or restricted by physical or institutional barriers

Parameters and maximum limits required

DBO <20 mg/L
RNFT (SST) ≤ 30 mg/L
E. coli <1000 cfu/100 mL

Figure 6. Comparison of AP5 WWTP effluent parameters with parameters and quality limits of international reuse legislation (EPA/USA and AGWR/Australia)

non-compliance are turbidity for Campinas (Class A) and Residual Chlorine for Campinas (Class B). Regarding the available quality parameters (BOD, TNFR, and pH) referring to AP5 WWTP effluents (unpolished for reuse), it appears that they do not only meet the limits of Campinas (Class A).

Despite the scarcity of more information on effluents to compare with the listed limits, it appears that there is also great potential for quality, since the quality results presented refer to the secondary effluent without any polishing.

Regarding the potential specifically for industrial use, Table 8 presents data on quality parameters required/recommended for application in cooling towers, comparing them with reuse water quality data from the Alegria and Penha WWTPs.

It is noted that the turbidity parameter is one of the few criteria that presents non-compliance, not meeting three references (Giordano, s/d; Jordão and Pessoa, 2014; PROSAB, 2006), as well as suspended solids, which do not comply with the limits recommended by Jordão and Pessoa (2014) and PROSAB (2006), highlighting that none of the above references has normative character.

Although they are data from spot analyzes and the few data available do not cover important parameters such as alkalinity, dissolved solids and hardness, making a broader comparison/evaluation impossible, it is found that there is also a good potential for reuse of these waters, even for more demanding purposes such as cooling towers.

Step 4: Evaluation of the results: potentialities, obstacles

Table 4. Comparison of limits of the researched legislation / standardization and results of monitoring of effluent and reuse waters of WWTP

Legislation / Reference Source	**BOD (mg/l)**	**TNFR (mg/l)**	**SDT (mg/l)**	**pH**	**Turbidity(1) UNT**	**Residual chlorine (mg/l)**	**Chlorides (mg/l)**	**E.Coli (Term) (UFC/ 100ml)**	**Giardia/ Cryptosp (cistos/l)**	**Helminth Eggs (egg/l)**
Class NBR13969/97 1(3)		<200	200	6 to 8	<5	0.5 to 1.5		<200		
Class NBR13969/97 2(4)					<5	0.5		<500		
Class NBR13969/97 3(5)					<10			<500		
Class NBR13969/97 4(2)								<5000		
Municipal law Niterói 2856/11			200		5			Absence		
Campinas Law Class A	5	5			1	min 1.0	250	<100	-	-
Campinas Law Class B	30	30			5	2.0	250	<200	0.05	<1
Res. SP 01/17 Use of severe restriction	<30	<30(1)	2000	6 to 9	-		350	<200	-	<1
Res. SP 01/17 severe restriction	<10	1(1)	450	6 to 9	<2		100	ND	-	<1
USEPA unrestricted use	<10	-		6 to 9	<2	≥1	-	ND	-	-
USEPA restricted use	≤30	≤30		6 to 9	<2	≥1	-	<200	-	-
PROSAB unrestricted use	-	-	-	-	-	-	-	≤ 200	-	≤ 1
PROSAB restricted use	-	-	-	-	-	-	-	≤ 1x 104	-	≤ 1
PROSAB Building use	-	-	-	-	-	-	-	≤ 1x 103	-	≤ 1
Reuse Water WWTP Alegria(11)	-	-	-	6.97/7.02	1.72/2.39	1.1	-		-	-
Reuse Water WWTP Penha (10)	8 and <5	7 and 4	-	7.3 and 7.4	4	-	-	ABSENT	-	-
Reuse Water WWTP Penha (6)	6,2	3	-	6.99	4.28	1.29	-	ABSENT(7)	-	-
AP5 Wastewater Monitoring Analysis Results										
Values / Parameters	BOD(12) (mg/l)	TNFR(12) (mg/l)	COD(13) mg/l	pH(12)	Turbidity(1) UNT	Residual chlorine (mg/l)	Chlorides (mg/l)	**E.Coli (Term) (UFC/ 100ml)**	**Giardia/ Cryptosp (cistos/l)**	Helminth Eggs (egg/l)
Weighted(9)	25.0	18.9	25.5	6.7	NP(8)	NP	NP	NP	NP	NP
Average	25.9	21.9	29.2	6.8	NP	NP	NP	NP	NP	NP
Maximum	75.0	96.0	32.8	7.4	NP	NP	NP	NP	NP	NP
Minimum	3.5	6.0	22.3	5.9	NP	NP	NP	NP	NP	NP

Sources: Campos, 2018; Obraczka and Leal, 2016; Pieroni, 2016; Ramos *et al.*, 2005; USEPA, 2012; and Vieira Neto and Oliveira,2008.

Notes: 1 – Turbidity Criteria must be met prior to disinfection. This criterion should be based on the average hourly Turbidity measurements within a 24 hour period. No hourly measurement shall exceed 5 UNT. If filter membrane systems are used, Turbidity should not exceed 0.2 UNT and Total Suspended Solids should be 0.5 mg/L as concentrations higher than these are indicative of system integrity problems. 2 – Irrigation of orchards, cereals, fodder, pasture for cattle and other crops through runoff or punctual irrigation system; Dissolved oxygen> 2.0 mg/L. 3 – Car washes and other uses in direct contact with the user, with possible aspiration of aerosols by the operator, including fountains; Residual chlorine: 0.5 to 1.5 mg/L. 4 – Cleaning of floors, sidewalks and garden irrigation, maintenance of lakes and landscaped canals, except fountains. Residual chlorine> 0.5 mg/L. 5 – Toilet flushing. 6 – Average results of analyzes performed in January 2013. 7 – Vieira Neto and Oliveira (2008). 8 – NP (not performed). 9 – It also takes into account the effective tributary flow rates of each WWTP. 10 – Results for 2005 and 2008 (Ramos et al, 2005 and Vieira Neto and Oliveira, 2008). 11 – Data available in Farias (2019). 12 – Average empirical data for monitoring WWTP evaluated by independent laboratory. 13 – Secondary data from the assessed WTPP SARs. 14 – Weighted COD based on SAR data for the five largest AP5 WWTPs.

Table 5. Quality parameters for reuse water for cooling tower applications.

Quality Parameters	Water in cooling towers								Reuse Waters	
	METCALF & EDDY (fresh water)		USEPA		FIESP	PROSAB	JORDÃO AND PESSOA	Giordano (cooling tower)		
	With recirculation	Without recirculation	With recirculation	Without recirculation		Polo Industrial Mauá With recirculation	AQUAPOLO		ETE Penha (1)	ETE Alegria
Chloride mg / L	600	500			500	70		100		
Dissolved Solids mg / L	1000	500			500	200		80		
Suspended Solids mg / L	5000	100	<30	<30	100	2	< 2	10	4 and 7/3	
Hardness mg / L CaCO3	850	130			650	70		100		
Alkalinity mg / L CaCO3	500	20			350	50		100		
pH	5.0 - 8.3		6-9	6-9	6.9-9	6.5-7.5		6.5-8.5	7.3 and 7.4/6.99	6.97/7.02
COD mg/L	75	75			75	2	< 20	20		
BOD mg/L			<30	<30	25		< 10	15	8 and <5/6.2	
Temperature ºC	38	38								
Turbidity NTU	5000				50	1	< 1	2	4.28/4	1.72/2.39
Fecal Coliforms un/100ml			<200	<200				ABSENCE	ABSENT	
Residual chlorine (Cl2) mg/L			1	1			> 0.5		1.29	1.1

Source: Pieroni (2016); Giordano(s/d); Ramos *et al.* (2005) and Vieira Neto and Oliveira (2008

Notes: 1- Two distinct data sources / campaigns; FIESP: São Paulo State Federation of Industries.).

and suggestions regarding the implementation of reuse in the municipality.

It is noted that there is a great potential for the use of water regenerated from WWTP in the city of Rio de Janeiro. Despite demands from various stakeholders, especially from larger consumers such as industries and large commercial ventures, such potential is not yet adequately studied – and certainly not exploited – by the two utilities.

In addition to Alegria, Penha and Deodoro, there are several other WWTPs located at strategic points of the city (Pavuna and Sepetiba) that continuously generate large flows of treated effluent with good characteristics for reuse, and can meet less stringent demands in terms of quality, with no need for major investments by utilities for greater effluent polishing. Even if an improvement is needed, it should not be a cost that would make it impossible to meet the demand or a nobler destination, thus setting a compatible price. It is noteworthy that a large part of the treatment costs is already embedded in the routine operation of the WWTPs to meet the release standards in the receiving bodies established by the environmental legislation of the state of Rio de Janeiro, the most restrictive in Brazil.

However, in the event of any increase in demand, the reuse water production capacity of existing systems (Penha, Alegria and Deodoro WWTPs) will need to be expanded. As the transportation of regenerated water is basically made using water trucks, this increase should be accompanied by the expansion of reservoir and loading capacity of water trucks in these WWTPs, including the improvement of the necessary logistics, such as providing larger parking and maneuvering areas for these vehicles.

Among the aspects that contribute to the current stage of incipient reuse in the scenario of the city of Rio de Janeiro, and which hinder its implementation, can be cited: (1) Lack of knowledge and a “culture” of reuse; (2) Lack of information and a database; (3) Lack of specific legislation and regulation, especially federal; (4) Absence of public policies, planning instruments and economic incentives; and (5) Physical obstacles, the distances between the main generating poles (larger WWTP) and some major poten-

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tial consumers of reuse water in the city of Rio de Janeiro, which add to the capacity/flow restrictions of the water supply system of water trucks.

5. CONCLUSIONS

The development of the research allowed a greater knowledge about the practice of reuse, focusing on providing an alternative water supply in the city of Rio de Janeiro. Considering public sanitation systems, reuse is still incipient, and is little known and accessible to most of the population as well as potential users/consumers.

From the collection of data on legislation and practical cases of reuse in the country, notably by corporations, as well as abroad (where it is consolidated as a water resources management tool and strategic alternative of water source, including for nobler purposes), it can be seen that in our reality it needs more regulation, in order to provide greater legal and institutional security, necessary for its implementation.

The identification/characterization of potential and effective generators (WWTP) and consumers (industries, bus garages, airport terminals, and utilities such as COMLURB) served as the basis for the preparation of an unprecedented inventory and reuse database in the municipality of Rio de Janeiro. From this database and the basic characterization of the quality of treated effluents and sewage reuse waters, such as Alegria and Penha, their comparison with limits recommended by the available legislation / standardization, in addition to surveying the costs of reuse water and the conventional system, it was possible to evaluate the viability of reuse and identify potentialities and bottlenecks with a view to expanding its use in the city of Rio de Janeiro.

It can be inferred that reuse is more feasible primarily for less noble and non-potable urban and industrial purposes due to the higher demand, high price of conventional drinking water and greater proximity between generating and consuming sources and the lower quality of reuse water required, consequently implying lower investments needed to polish the treated effluent.

Larger industrial/commercial developments, located in urban areas and closer to WWTPs, such as Alegria and Penha (AP1) and Deodoro (AP5), are configured as higher potential consumers and transport can be carried out by tanker truck, since there is an expansion in the capacity to meet these demands in the referred WWTPs, in case of greater demand for regenerated waters. Due to the high costs, most of these large companies no longer use water from the conventional system.

Not yet commercialized and considered by the concessionaires basically as “waste to be properly disposed” in the receiving bodies, the treated effluents, however, have potential for sale, and may constitute an additional source of revenue for these sanitation companies, since most of the cost is already inserted in the system to adapt the raw tributary to the demands for launching in the receiving bodies. Such revenues may even contribute to the investments required to increase production and/or improve the quality of the currently produced regenerated water, aiming to meet possible demands / more discerning consumers.

In a reality where a large part of the population does not even have sewage collection, it is estimated that investments in basic sanitation are directed to the expansion / universalization of these services. However, reuse must also be prioritized because it is a strategic alternative for water supply, increasing water security. The implementation of reuse in the city of Rio de Janeiro can improve water resources management by providing a water source alternative for less noble uses, especially in locations and times of greater scarcity and/or difficulties in supply by the conventional system. As a result, the increasing pressures on existing water sources and systems are reduced, delaying many investments needed to expand conventional water supply systems.

Among the restrictions observed in the development of this study, the difficulty of obtaining more effluent quality data from the generating sources (WWTP) stands out. Even in the case of highly relevant indices, it was not possible to better evaluate the bacteriological parameters, due to the lack of secondary data and limitations of the Sanitary Engineering laboratory (SEL) to perform certain analyzes.

Parameters such as coliforms, Helminth eggs, Giardia and *Cryptosporidium* are mandatory monitoring criteria in the legislation of countries that are reference in reuse (USA, Australia, Singapore), which have already prioritized potabilization, requiring much more rigorous and comprehensive control of the quality of the water produced.

There were also difficulties in obtaining more data on flow rates and quality of regenerated water to characterize and meet specific demands of potential consumers, such as those in the industrial sector. Such impediment can be partially circumvented through a differentiated approach by industrial sector and/or locality, as it is a specific case that has been studied for the reuse water supply of WWTP Alegria for kneading in the Caju concrete plants.

Aiming to implement the reuse and improvement of water resources management, the following measures may be suggested/highlighted: 1) further knowledge and

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dissemination of monitoring data, studies and research, supporting the proposition/execution of actions for the dissemination and operationalization of reuse systems in the city of Rio de Janeiro and its metropolitan region; 2) greater regulation of reuse; 3) insertion of concepts, such as symbiosis and industrial ecology, in the urban/environmental planning system; and 4) greater incentives, including economic incentives, for the use of regenerated waters.

Also noteworthy is the importance of a more comprehensive (holistic) assessment of the actual costs of implementing/operating a treatment system, when planning/designing it, including expenses for the proper disposal of waste generated. Accounting for possible reuse and sale of treated effluents over the project horizon may significantly change the balance between costs and benefits of the alternatives evaluated, favoring those that favor reuse.

As a result of the research, it is emphasized the need to expand the inventory just started, with the insertion of more data on actual/potential generators and consumers of reused water.

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