Water reuse potential for irrigation in Brazilian hydrographic regions

Maíra Lima, Bruna Magalhães de Araujo, Sérgio Rodrigues Ayrimoraes Soares, Ana Silvia Pereira Santos and José Manuel Pereira Vieira

ABSTRACT

The present paper carried out an evaluation of the reuse potential of the Wastewater Treatment Plants (WWTPs) effluents for irrigation in the 12 Brazilian Hydrographic Regions (BHRs). For this purpose, initially, the WWTPs were categorized and the effluent flow rate was estimated. Category 1 represents secondary effluent with an efficiency of organic matter removal greater than 80%; Category 2 represents effluent that underwent some disinfection step; and effluents that perform less than the other categories were called 'Uncategorized'. After that, the irrigation water demands for each BHRs were compiled, and finally, the production of water for reutilization was compared with the demand for irrigation. Thus, it was observed that all the sewage flow rates generated in Brazil classified in Categories 1 and 2 represent 9% of the total irrigation water demand in the country (1,078.71 m^3/s) and it stands out that only 7% of the flows treated in Brazil undergo a tertiary treatment step.

Key words | Brazilian Hydrographic Regions, irrigation water demand, wastewater treatment plant, water availability, water resources management, water reuse

Maíra Lima (corresponding author)
Bruna Magalhães de Araujo
Ana Silvia Pereira Santos
Engenharia Ambiental e Sanitária, Depto. de Eng. Sanitária e Meio Ambiente,
Universidade do Estado do Rio de Janeiro,
Rio de Janeiro, RJ,
Brazil
E-mail: *mairalima.90@gmail.com*

Sérgio Rodrigues Ayrimoraes Soares
Agência Nacional de Águas,
Rio de Janeiro,
Brazil

José Manuel Pereira Vieira
University of Minho

HIGHLIGHTS

- In Brazil, irrigation demands 52% of water withdrawals.
- There are 12 BHRs for guiding the management of water resources.
- Flow rate of WWTP effluent with an organic matter removal efficiency greater than 80% represents 9% of the total water demand for irrigation.
- There are some BHRs with a high potential of reuse for irrigation.
- Some BHRs present high demand for irrigation, but with low sewage treatment coverage.

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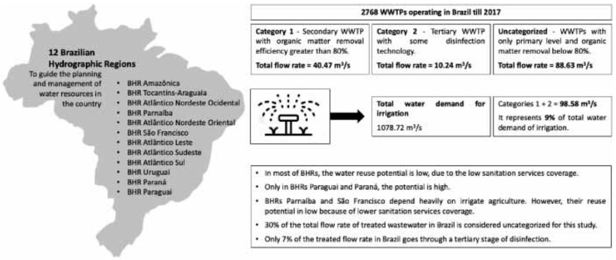
GRAPHICAL ABSTRACT



2768 WWTPs operating in Brazil till 2017

Category 1 - Secondary WWTP with organic matter removal efficiency greater than 80%.
Total flow rate = 40.47 m³/s

Category 2 - Tertiary WWTP with some disinfection technology.
Total flow rate = 10.24 m³/s

Uncategorized - WWTPs with only primary level and organic matter removal below 80%.
Total flow rate = 88.63 m³/s

Total water demand for irrigation
1078.72 m³/s

Categories 1 + 2 = **98.58 m³/s**
It represents **9%** of total water demand of irrigation.

- In most of BHRs, the water reuse potential is low, due to the low sanitation services coverage.
- Only in BHRs Paraguai and Paraná, the potential is high.
- BHRs Parnaíba and São Francisco depend heavily on irrigate agriculture. However, their reuse potential in low because of lower sanitation services coverage.
- 30% of the total flow rate of treated wastewater in Brazil is considered uncategorized for this study.
- Only 7% of the treated flow rate in Brazil goes through a tertiary stage of disinfection.

INTRODUCTION

Although Brazil has large water reserves, about 12–16% of the total amount available in the world (Ramos 2016), its water availability is not evenly distributed throughout its territory. Approximately 260 thousand m^3/s of water flows through Brazilian territory and of this amount, 80% is in the Amazon region, where there is the smallest portion of the population and the lowest water use demand (ANA 2018).

This context, which can become even more complex in a scenario of climate change and increased water use, leads to water stress in some regions of Brazil, like currently in the Southeast (ANA 2018). In the Semi-Arid Region, which covers the states of the northeast region (Alagoas, Bahia, Ceará, Paraíba, Pernambuco, Piauí, Rio Grande do Norte, and Sergipe), in addition to the north of the Minas Gerais state, the water scarcity is historic. Thus, this region has one of the lowest socioeconomic development rates in the country. The surface water availability in Brazilian territory is presented in Figure 1, with emphasis on the Semi-Arid region.

In 2003, according to Resolution No. 32 of the National Water Resources Council (Brazil 2003), Brazilian territory was divided into 12 Brazilian Hydrographic Regions (BHRs), with the objective of guiding the water resources planning and management in the country: (1) Amazônica, (2) Tocantins-Araguaia, (3) Atlântico Nordeste Ocidental, (4) Parnaíba, (5) Atlântico Nordeste Oriental, (6) São Francisco, (7) Atlântico Leste, (8) Atlântico Sudeste, (9) Paraná, (10) Uruguai, (11) Atlântico Sul, and (12) Paraguai. The 12 BHRs are represented in the map in Figure 2. The main characteristics of the 12 BHRs are shown in Table 1.

The BHRs with the most critical water levels are Atlântico Nordeste Oriental, located in the Semiarid Region; and Atlântico Sul, which has extremely high water demand for irrigation. In addition, BHRs Atlântico Leste and São Francisco have high water demands in comparison with their water availability (ANA 2018).

Throughout the world, due to water scarcity and the increase in water use conflicts, water conservation and reuse have gained prominence as water resource management tools (Angelakis *et al.* 2018). In addition, population growth, climate instability, and increased demand for food culminated in a scarcity of water of adequate quality for irrigation (Ahmadi & Merkley 2017; Maryam & Buyukgungor 2019).

The water reuse for irrigation purposes was already adopted in the world since the prehistoric period to the current, considering different aims and perspectives throughout these years (Mays *et al.* 2007; Angelakis & Spyridakis 2013; Angelakis *et al.* 2018). Nowadays, irrigated agriculture accounts for approximately 70% of total freshwater in the world, and this value is even higher in many developing countries (Peng *et al.* 2019). In Brazil, according to ANA (2019), irrigation demands about 52% of water withdrawals, followed by urban supply, the processing industry and animal supply.

Thus, the main destination of reclaimed water in the world is irrigated agriculture (Angelakis *et al.* 2018). However, it is important to highlight that this reclaimed water comes mainly from wastewater treatment plants (WWTPs). It is estimated that more than 10% of the world's population consumes agricultural products produced through wastewater irrigation (Jeong *et al.* 2016).

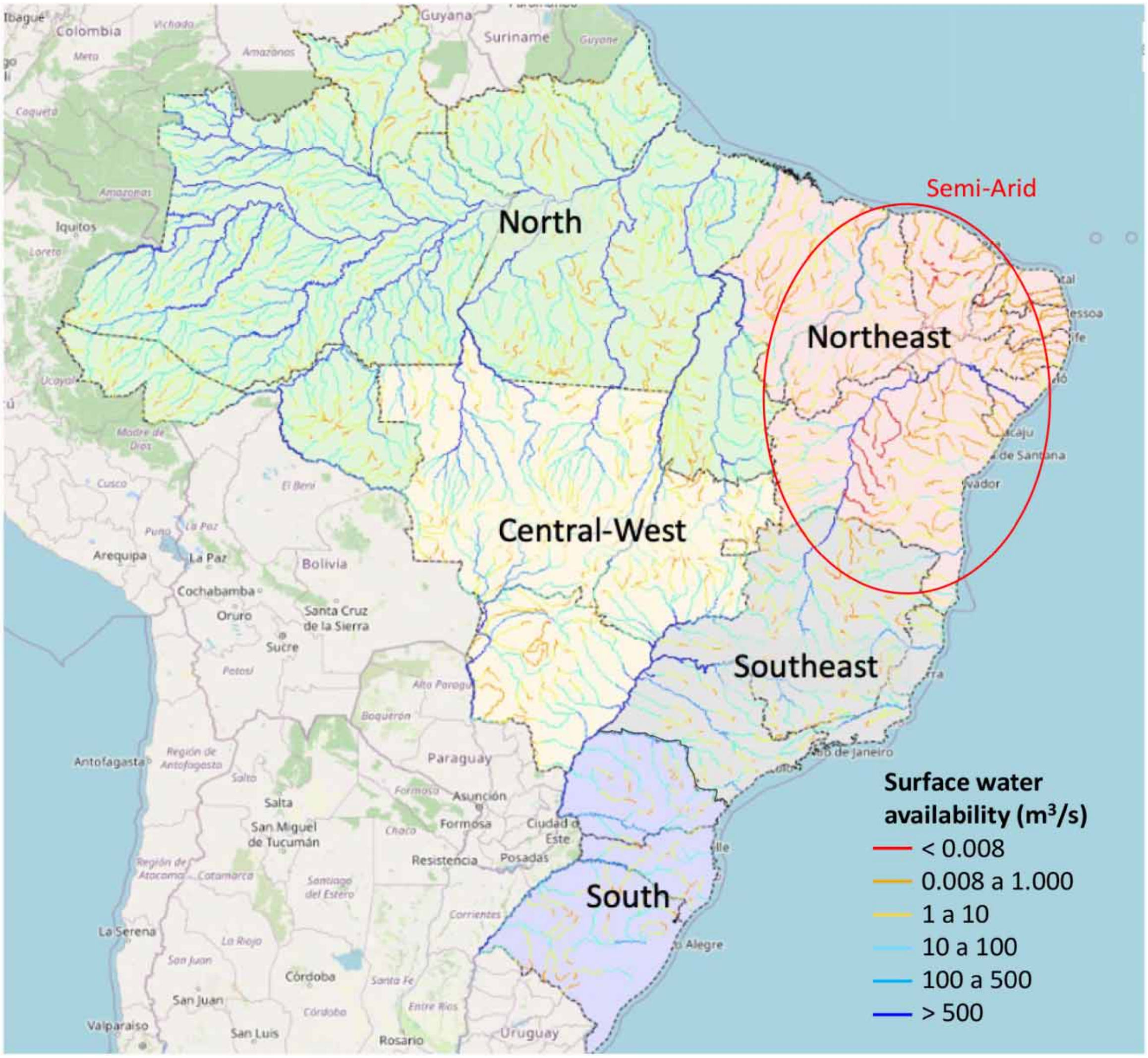


Figure 1 | Surface water availability in Brazil – highlights for the Semi-Arid region – modified from INDE (2020).

Regions with high rates of wastewater treatment have, theoretically, a greater potential for generating water for reutilization. This is the case in Israel, which treats 97% of the wastewater generated and reuses 80% of it in irrigation, supplying 40% of the demand for this purpose (Marin *et al.* 2017). In Brazil, only 42.6% of the wastewater generated is treated (ANA 2017), reducing its potential for reuse.

In general, water reuse in agriculture becomes an effective alternative source of water for production of different crops and also the supply of nutrients in the practice of fertigation (Maryam & Buyukgungor 2019). However, negative aspects such as the accumulation of substances that hinder plant growth, the potential damage to the soil through the transformation of its physical-chemical characteristics, and contamination by microorganisms must be evaluated (Xu *et al.* 2010).

The quality required for irrigation depends mainly on the type of consumption, cultivation, and irrigation for each crop. This quality requirement is related to the greater or lesser possibility of microbiological contamination, both from users and workers and from the soil (Beaudequin *et al.* 2015; Chhipi-Shrestha *et al.* 2017; Rock *et al.* 2018).

According to Maryam & Buyukgungor (2019), primary effluent is not recommended for reuse in agriculture;

Figure 2 | Distribution of Brazilian Hydrographic Regions and representation of the federative units – modified from ANA (2017).

secondary effluent (biological oxidation) is recommended for surface irrigation of orchards and vineyards and non-food crop irrigation; tertiary effluent (chemical coagulation, nutrient removal, filtration, and disinfection) is recommended for food crop irrigation. However, Tsagarakis *et al.* (2013) suggest that even primary treatment effluent can be used in controlled irrigation, if adequate precautionary and safety measures are taken.

Thus, the present work aims to evaluate, in a preliminary way, the potential of reuse for irrigation, of the effluents from all of wastewater treatment plants operating in Brazil (2,768 facilities) and allocated in the 12 different Brazilian Hydrographic Regions.

MATERIAL AND METHODS

The study was developed in three stages (Figure 3), as of the consolidation of public data presented in national documents (Table 2) related to all of the wastewater treatment plants in operation (2,768 facilities) and to the water demands for irrigation in each BHR.

Table 1 | Main characteristics of Brazilian hydrographic regions (Veiga & Magrini 2013)

Brazilian hydrographic regions	**Area (km^2)**	**States**[a]	**Population (10^6)**	**Main river basins**
Atlântico Sudeste	214,629	MG, ES, RJ, SP, PR	27.4	Paraíba do Sul, Doce
Paraná	879,873	SP, PR, MS, MG, GO, SC, DF	61.0	Paraná, Grande, Capivari, Jundiaí, Paranapanem, Piracicaba
São Francisco	638,576	BA, MG, PE, AL, SE, GO, DF	13.9	São Francisco
Atlântico Nordeste Oriental	286,802	PI, CE, RN, PB, PE, AL	23.4	Capibaribe, Una, Paraíba, Jaguaribe, Acaraú
Amazônica	3,869,953	AC, AM, RO, RR, AP, PA, MT	9.1	Amazonas
Tocantins-Araguaia	921,921	GO, TO, PA, MA, MT, DF	8.0	Tocantins, Araguaia
Parnaíba	333,056	PI, MA, CE	4.0	Parnaíba
Atlântico Nordeste Ocidental	274,301	MA, PA	5.8	Gurupi, Munim, Mearim, Itapecuru,
Uruguai	174,533	RS, SC	4.0	Uruguai
Paraguai	363,446	MT, MS	2.0	Paraguai
Atântico Sul	187,552	SP, PR, SC, RS	13.0	Itajai, Capivari, Taquari-Antas, Jacuí, Vacacaí, Camaquã, Lagoa Mirim, Patos
Atlântico Leste	388,160	BA, MG, SE, ES	15.1	Paraguaçu, Pardo, Contas, Salinas, Mucuri, Itapecuru, Jequitinhonha

[a] AC – Acre, AL – Alagoas, AP – Amapá, AM – Amazonas, BA – Bahia, CE – Ceará, ES – Esp + iruto Santo, GO – Goiás, MA – Maranhão, MT – Mato Grosso, MS – Mato Grosso do Sul, MG – Minas Gerais, PA – Pará, PB – Paraíba, PE – Pernambuco, PI – Piauí, RJ, Rio de Janeiro, RN – Rio Grande do norte, RS – Rio Grande do Sul, RO – Rondônia, RR – Roraima, SC – Santa Catarina, SP – São Paulo, SE – Sergipe, TO – Tocantins, DF – Distrito Federal.

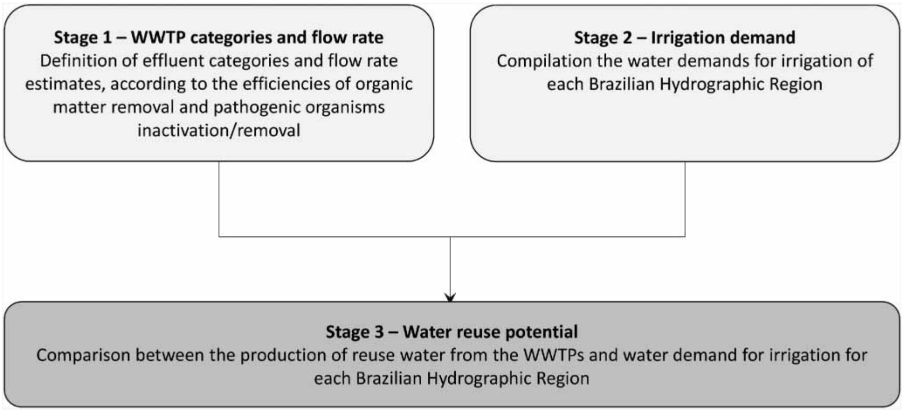


Figure 3 | Flowchart of the steps adopted in the research.

Table 2 | Main national public documents used in data generation of the research

N°	**Document title (original and translation)**	**Description**	**Source**
1	*Atlas esgotos: despoluição de bacias hidrográficas* (Wastewater atlas: river basins depollution)	It gathers the wastewater diagnosis of all 5,570 urban municipalities in Brazil, the impact of the effluent discharging and the planning for the wastewater treatment, with data to 2013	ANA (2017)
2	*Manual de usos consuntivos da água no Brasil* (Manual of consumptive water uses in Brazil)	It contemplates the definition of methods, the construction of a database beyond the production, storage, and availability of estimates consumptive water uses for all Brazilian municipalities	ANA (2019)

Stage 1 – definition of WWTP categories and flow rate estimative

For this stage of the research, the following data was extracted from document 1 (Wastewater atlas: water basins depollution), for each Brazilian municipality: (i) existence of WWTP; (ii) efficiency in organic matter removal; (iii) treatment technologies adopted in the WWTP; (iv) operational flow rate.

Subsequently, study categories were defined in relation to the performance of organic matter removal and pathogenic organisms' removal/inactivation. This categorization aimed to classify effluents in two situations:

- Category 1 – Secondary WWTP with organic matter removal efficiency greater than 80%: To produce effluent available to reuse in most of crops, it would be needed only to include a disinfection tertiary step.
- Category 2 – Tertiary WWTP with some disinfection technology (mostly maturation ponds): Effluent can be distributed for direct reuse for the irrigation of most crops.

The WWTPs with only primary level or only UASB (upflow anaerobic sludge blanket) reactor and organic matter removal efficiency below 80% were not categorized. They were considered for this study as 'uncategorized' because these facilities require high investments to adapt the effluent to reuse, since they would still need a secondary stage or a polishing prior to disinfection.

It is important to discuss the issue of the type of crop to be irrigated and, therefore, the quality of the water required for this purpose. In this sense, this article does not consider a discussion in relation to water quality standards, but rather evaluates possibilities for reuse depending on demand and supply in different qualities. These qualities are represented here according to the categories defined for the study and previously mentioned.

Stage 2 – irrigation water demand

For this stage of the research, the data of water demand for irrigation for each BHR were extracted and compiled from document 2 (Atlas irrigation: water use in irrigated agriculture).

The water demand for irrigation varies depending on some factors, such as rainfall regime (spatial and temporal distribution), evapotranspiration rates, seasonality, amount of water required depending on the crop to be irrigated, quality of the soil, soil capacity of water storage and the types of irrigation.

Stage 3 – water reuse potential

In this stage, a comparison was made between the flow rate data of the WWTPs, according to Categories 1 and 2, defined in Stage 1 and the water demand for irrigation in each Hydrographic Region compiled in Stage 2. Finally, it was possible to accomplish a critical analysis of the management of water resources in Brazil and the inclusion of water reuse in the national water matrix.

RESULTS AND DISCUSSION

Stage 1 – definition of WWTP categories and flow rate estimative

Initially, all the WWTPs in operation in the country were allocated in their respective Brazilian Hydrographic Regions. Furthermore, the WWTP flow rates were divided into the two categories described in the methodology.

Table 3 shows both the effluent flow rates from the WWTPs divided into the two categories (01 and 02), as well as the flows classified as 'uncategorized', in each of the 12 Brazilian Hydrographic Regions.

The Paraná Hydrographic Region has an area of approximately 10% of the national territory and covers the states of São Paulo, Paraná, Mato Grosso do Sul, Minas Gerais, Goiás, Santa Catarina, and Federal District. BHR Paraná is of great importance at national level since it is the region with the greatest economic development in the country and it also presents the greatest demand for resources (ANA 2015). In this way, it is observed that in this BHR there are the highest WWTP total flows and by category compared to the others. According to ANA (2015), its population is predominantly urban, with around 93% of the total of its inhabitants.

Table 3 | Distribution of WWTPs flow rates in Brazilian Hydrographic Regions, and the categories defined in the study

Brazilian Hydrographic Region	**Total flow rate (m^3/s)**			
	Uncategorized	**Category 1**	**Category 2**	**Total**
Amazônica	0.92	0.37	0.18	1.47
Atlântico Leste	0.48	0.93	0.94	2.35
Atlântico Nordeste Ocidental	0.18	0.01	0.06	0.25
Atlântico Nordeste Oriental	4.31	4.60	0.69	9.59
Atlântico Sudeste	5.07	11.69	0.86	17.62
Atlântico Sul	3.36	1.74	0.33	5.43
Paraguai	0.55	1.30	0.13	1.97
Paraná	21.32	57.88	5.50	84.70
Parnaíba	0.24	0.02	0.33	0.58
São Francisco	3.26	9.30	0.45	13.01
Tocantins-Araguaia	0.43	0.34	0.70	1.47
Uruguai	0.35	0.45	0.09	0.89

The second BHR with the highest total effluent flow rate is Atlântico Sudeste. This region has the second largest population in Brazil and a great urban concentration (92% of the total) (ANA 2015). However, in relation to Category 2, its flow rate is lower than that generated at HR Atlântico Leste. This is because, in the latter, there are 15 large WWTPs that include maturation ponds in their flowcharts.

HR Atlântico Nordeste Ocidental presents considerably reduced effluent flow rates due to the low sewage collection and treatment rates in the region: 28% of the sewage is collected and only 8% of the total generated is treated (ANA 2015). In this case, almost the entire state of Maranhão is in this region. Its most important city, the capital São Luís, has only 4% of treated wastewater, according to ANA (2017). Although the second largest municipality, the state of Maranhão, presents 100% of sewerage service covered, 95% of the population is served with septic tanks and only 5% with collection and treatment through the centralized system (ANA 2017).

In all BHRs except four (Atlântico Leste, Atlântico Nordeste Ocidental, Parnaíba, and Tocantins-Araguaia), the flow rates corresponding to Category 2 are lower to those of Category 1. This demonstrates little commitment of environmental sanitation management to adopt WWTPs with a disinfection stage in Brazil. It is also noticed that around 7% of the flow rate treated in Brazil goes through a tertiary stage of disinfection. It is noteworthy that in this country, there is a huge gap in the application of integrated wastewater management – IWM (centralized and decentralized) and integrated water and wastewater management – IWWM. According to Angelakis *et al.* (2018), IWM and IWWM are important trends in the environmental engineering and water resources field. Finally, the concept of 'one water' should merge individual water and wastewater departments into one unique department to develop more thoughtful, rational, and cost-effective solutions to meet future water needs.

Another unsatisfactory scenario is related to the BHRs that have flow rates allocated in the item 'Uncategorized', higher than the flows of Categories 1 and 2. This occurs in the BHRs Amazônica, Atlântico Nordeste Ocidental, and Atlântico Sul. This means that almost 30% of the total wastewater treated in Brazil corresponds only to the primary or advanced primary stages.

In this discussion, the importance of increasing wastewater treatment coverage rates is highlighted, not only in the sense of compliance with the national guidelines for effluent discharges, but also in relation to the production of higher volumes of water for reutilization. This action could be the target of areas with lower rates of socioeconomic development (Maryam & Buyukgungor 2019).

Stage 2 – irrigation water demand

The flow rate values corresponding to the water demands for irrigation of each BHR are shown in the schematic drawing and the graphic representation of Figure 4.

According to Figure 4, in the south of Brazil there is intense activity focused on irrigation, with high demand for this use in the BHRs Atlântico Sul, Uruguai and Paraná. It should be noted that in BHR Paraná there is the largest irrigated area in the country, corresponding to 36% of the total (ANA 2015).

In the northeast of the country, high demand for irrigation is observed only in BHR São Francisco, which has approximately half of its area in the Semi-Arid region. It is estimated that this area represents 10.9% of the total irrigated area in Brazil (ANA 2015).

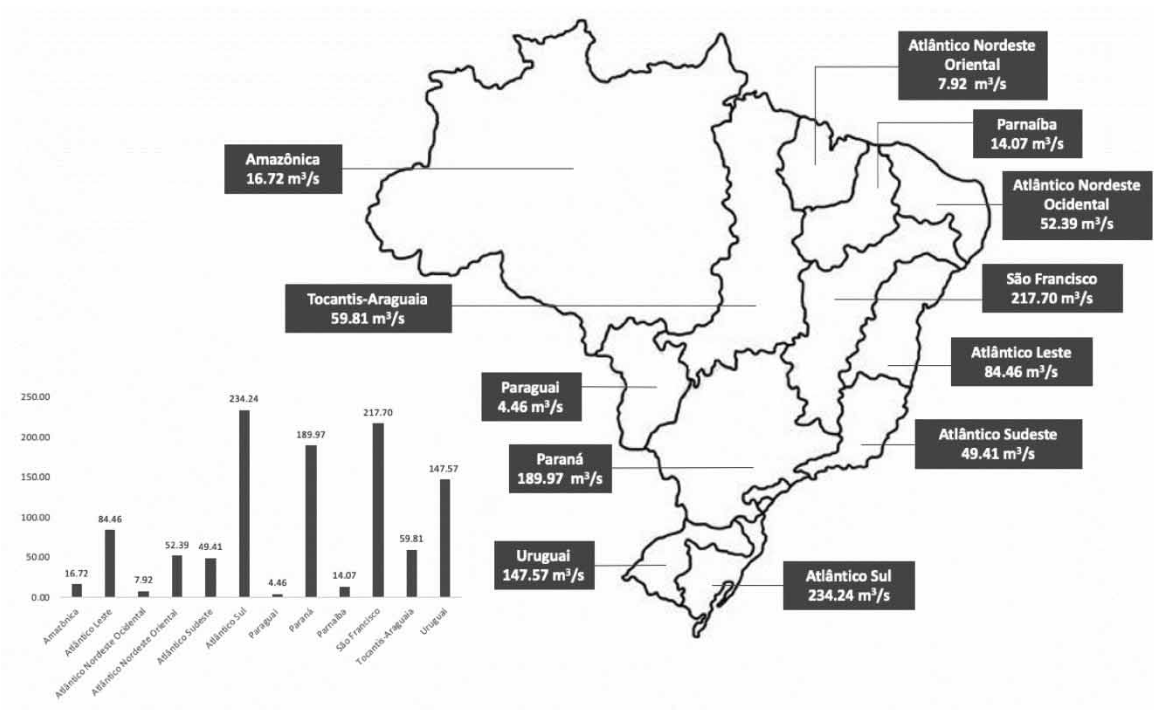


Figure 4 | Graphical representation and schematic drawing of the flow rates corresponding to the irrigation water demands for the Brazilian Hydrographic Regions.

There is lower water demand for irrigation in BHRs Paraguai, Parnaíba, and Amazônica. Much of the BHR Paraguai area is occupied by the Pantanal biome, characterized by well-defined periods of flood and drought and the main activity in this region is livestock (ANA 2015; Figueiredo *et al.* 2016). BHR Parnaíba has irrigated agriculture as its main activity. However, its bigger part is within in the Brazilian Semi-Arid region and presents characteristics of intermittent rainfall. Thus, there is a need to encourage alternative sources of water to increase the region's socioeconomic development. BHR Amazônica has a great extent of forest, with 85% of its territory occupied by native vegetation, and many of the cultivated crops do not require irrigation (ANA 2015).

For other regions, water demand for irrigation varies between 48.41 m^3/s in the BHR Atlântico Sudeste and 84.46 m^3/s in the BHR Atlântico Leste. In BHR Atlântico Leste, low water availability and intermittency of most rivers may become limiting for the expansion of agricultural activities. Thus, the availability of alternative sources of water such as water for reuse can leverage the socioeconomic development of the region. Finally, BHR Tocantins-Araguaia is important in the national context, as it is characterized by the expansion of the agricultural frontier. This expansion could be more accentuated with the inclusion of other sources of water for irrigation, since most of the current irrigated area is private (97%), fostering the potential for reuse for the development of agribusiness (ANA 2015, 2018).

Stage 3 – water reuse potential

Table 4 shows the water demand values for irrigation and effluent flow rates divided into the categories defined for the study, in each Brazilian Hydrographic Region. The values referring to uncategorized flow rates are not included in this session.

In general, in all BHRs, the effluent flow rates of Category 1 and/or Category 2 are significantly lower than the water demand for irrigation. However, it is noteworthy that for BHRs Atlântico Sudeste, Paraguai and Paraná, the effluent flows of Category 1 represent approximately 24, 29, and 30% of the water demand of irrigation, respectively. In relation to Category 2, none of effluent flow rates reaches more than 3% of demand and the one with the highest ratio is HR Paraná with 2.9%.

Table 4 | Distribution of water demands for irrigation and WWTP effluent flow rates in each category for BHRs

		Total flow rate (m^3/s)	
Brazilian Hydrographic Region	**Water demand for irrigation (m^3/s)**	**Category 1**	**Category 2**
Amazônica	16.72	0.37	0.18
Atlântico Leste	84.46	0.93	0.94
Atlântico Nordeste Ocidental	7.92	0.01	0.06
Atlântico Nordeste Oriental	52.39	4.60	0.69
Atlântico Sudeste	49.41	11.69	0.86
Atlântico Sul	234.24	1.74	0.33
Paraguai	4.46	1.30	0.13
Paraná	189.97	57.88	5.50
Parnaíba	14.07	0.02	0.33
São Francisco	217.70	9.30	0.45
Tocantins-Araguaia	59.81	0.34	0.70
Uruguai	147.57	0.45	0.09

In order to facilitate understanding and include new questions for discussion, in Figure 5, the following data are presented graphically for each Brazilian Hydrographic Region: (i) irrigation demand; (ii) effluent flow rate considered as 'uncategorized'; (iii) effluent flow rate in Category 1; (iv) effluent flow rate in Category 2; and (v) total effluent flow rate corresponding to the summation between flow rates of Categories 1 and 2.

At BHR Paraná, the total flow corresponding to the sum of Categories 1 and 2 is 63.38 m^3/s and represents 33% of the water demand for irrigation. If 'uncategorized' WWTPs were to be added to this total, with their due interventions to adjust the effluent, this value would be 44%. It should be noted that this is a considerable percentual and, therefore, the governance of this region should add this issue to the planning of water resources. Still, it is important to highlight that, because it is the most developed region in the country. The supply of an alternative source of water for irrigation could not only lead to economic growth but also the

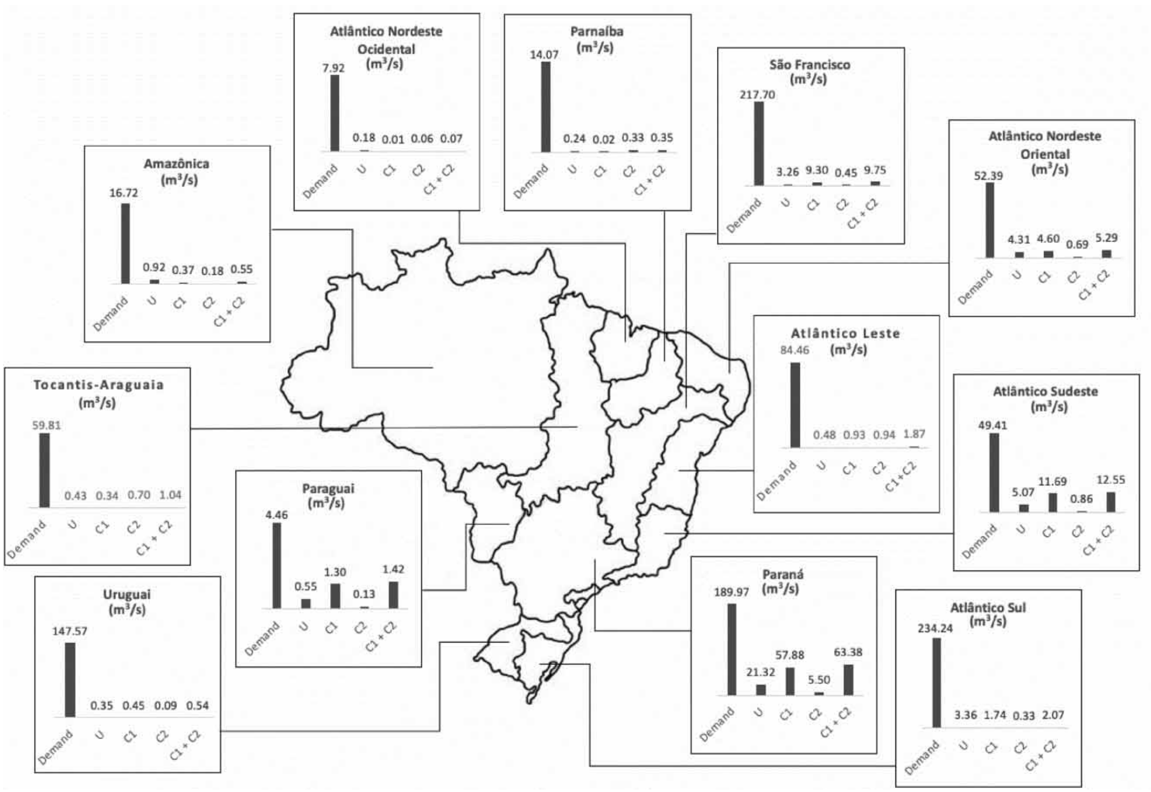


Figure 5 | Graphical and schematic representation of the flow rates corresponding to the water demands for irrigation and the effluent flow rates of WWTP for each BHR, distributed in three categories of the study. *Note*: U – Uncategorized. C1 – Category 1. C2 – Category 2.C1 + C2 – Category 1 plus Category 2.

reduction of conflicts over the use of water (Nölting & Mann 2018).

At BHR Paraguai, the uncategorized effluent (representing 12% of the water demand for irrigation) added to the effluents of Categories 1 and 2 represent 44%, similarly to HR Paraná. The water demand for irrigation in this BHR is only 4.46 m^3/s and in BHR Paraná is 189.97 m^3/s. Thus, there is a need to adapt these WWTPs (uncategorized), not only to comply with the current legislation on effluent discharges, but also to structure reuse planning in emergency situations.

The BHR Atlântico Sudeste also deserves to be highlighted for its high potential for the adoption of water reuse in irrigation. The flow rates of Categories 1 and 2 combined represent 25% of water demand for irrigation. When the 'uncategorized' flow rate is added, this ratio increases to 35%. Again, the discussion supports the need for more attention to WWTPs and their performance.

In the 12 HRs, eight of them (Amazônica, Atlântico Leste, Atlântico Nordeste Ocidental, Atlântico Sul, Parnaíba, São Francisco, Tocantins-Araguaia and Uruguai) present ratios of Categories 1 and 2 flow rates below 5% of the water demand for irrigation. This scenario demonstrates the country's fragility in relation to wastewater treatment and, consequently, the generation of water for reutilization as an alternative source for the irrigation of several crops. It is observed that the water demand in these regions is not high; actually, the wastewater treatment rates are low. This is the case, for example, of BHR Parnaíba, where the sewage collection rate in 2012 was 18%, the lowest among the 12 Brazilian Hydrographic Regions, as mentioned by ANA (2015).

Regarding the sanitary deficit faced in Brazil and the imminent need to apply the practice of water reuse to minimize the drought impacts that will be aggravated by climate changes and water use growth, the need to achieve universal sanitation is evident. This is not only to minimize the pollution of water bodies, but also to provide, in quantitative terms, effluents treated for the practice of water reuse.

In the Brazilian Semi-Arid region, the driest area in the country, 470 municipalities have intermittent or ephemeral water bodies. Thus, in addition to the need to remove BOD (Biochemical Oxygen Demand), it is important to take into account the practice of water reuse and/or prioritize treatment processes that result in high removal and inactivation of pathogenic microorganisms (ANA 2017).

The BHR Nordeste Oriental has a relative potential for water reuse in irrigation. For this, Category 1 effluent represents 9% of the water demand and if added to the 'uncategorized' effluent, this ratio becomes 17%. Apparently, this is a good percentual. However, the Category 2 rate represents less than 2%. Again, it demonstrates the fragility in terms of tertiary effluent generation, with good performance in relation to the removal and inactivation of pathogenic organisms.

The BHR Uruguai has the fourth largest water demand for irrigation in the country. However, the sum of all effluent flow rates, including 'uncategorized' ones, represents less than 1% of this demand. Thus, the need for adequate planning for the generation of water for reutilization is highlighted, with the aim of achieving universalization.

According to the results presented in Table 4, it can be observed that, hypothetically, if all the WWTPs in Categories 1 and 2 reused 100% of their effluents, it would be possible to produce almost 100,000 liters of water for reutilization per second, substantially reducing the amount of water captured from the sources. Although this statement seems inaccessible, it is worth remembering that Israel reuses 87% of all the effluent generated in the country (Marin *et al.* 2017).

Angelakis *et al.* (2018) indicate some important issues and challenges will need to be resolved to optimize water reclamation and reuse: (a) the development of more effective techniques and methods incorporating risk assessment to assess human and environmental health effects of wastewater constituents, and (b) the development of appropriate water reclamation and reuse regulations, applicable to different situations, which will both help to promote reuse as well as regulate it. However, there is still no adequate framework in Brazil for laws that regulate the practice of water reuse in the country.

CONCLUSION

Generally, in quantitative terms, the WWTPs in operation in Brazil generate 88.18 m^3/s of effluent in Category 1 and 10.24 m^3/s in Category 2. These values in total represent 9% of the total water demand for irrigation in the country (1,078.71 m^3/s).

Only in two Brazilian Hydrographic Regions (Paraná and Paraguai), is the installed potential high, around 44% of demand, considering the effluents from all categories. However, in most of them, the potential is low, due to the low attendance rates in relation to sanitation.

In situations where the installed potential is high, it is necessary to consider the operational levels of the WWTPs, to guarantee an adequate quality for reuse. In cases of low installed potential, it is necessary to assess the capacity to implement complementary units for such a practice, in addition to advances in service rates, with a view to universalization and water security.

The Brazilian Hydrographic Regions Parnaíba and São Francisco depend heavily on irrigated agriculture. Thus, water scarcity can curb socioeconomic growth of these regions, bringing water for reutilization with an important planning factor. In these two cases, the intermittent rainfall accompanied by climate change and population growth aggravate the situation. Furthermore, the sanitation services coverage is low and must be assessed for adequate water resources and sanitation management.

Only 7% of the treated wastewater flow rate in Brazil goes through a tertiary stage of disinfection, showing a fragility in relation to the quality of the effluent both for discharging and for the application of the practice of water reuse.

It is reinforced that the present work took into consideration only the amount of effluent generated in relation to the water demand for irrigation in each Brazilian Hydrographic Region. Thus, it is concluded that for the effective adoption of the practice of water reuse in planning, it is necessary to take into account the locations of both WWTPs, irrigated fields and transport, and storage logistics, in addition to the different levels of quality required for each type of culture. Still, in this work, an estimate with punctual flows was adopted. However, these flow rates that represent demands can occur on a seasonal basis in irrigation.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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