Systematic review of the last 20 years of research on decentralized domestic wastewater treatment in Brazil: state of the art and potentials

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ABSTRACT

A DEWATS (decentralized wastewater treatment system) is an alternative for expanding sanitation. In Brazil, DEWATS is acknowledged by law and is part of the National Sanitation Plan strategy for achieving the treatment of 85.6% of all the generated wastewater by 2033, improving the current treatment index of 49%. This review’s aim is to identify DEWATS studies in Brazil and to verify their potential for narrowing the national wastewater treatment deficit. Hence, aspects such as cost, maintenance, and efficiency were assessed. The archival research method (ARM) was used to identify papers published in the last 20 years through the scientific databases of Scopus, Science Direct, and Web of Science. Data regarding the general characteristics of each study were collected and compared to Brazilian environmental regulation and sanitation status. The results showed the evaluation of different technologies such as DEWATS, highlighting their flexibility and potential use in 79% of Brazilian counties. However, although 81% of the studies conducted performance analysis, none covered the main parameters required by Brazilian law. Although legal gaps for DEWATS improvement and consolidation have been identified and the interest in studying DEWATS has been increasing in the last five years, many barriers to their widespread use remain.

Key words: decentralized systems, decentralized wastewater systems, DEWATS, sanitation, sanitation in Brazil, wastewater treatment

HIGHLIGHTS

- Critical analysis on current challenges for the widespread use of DEWATS in Brazil.
- Studies focus on solutions for rural areas, highlighting the need for solutions in urban and peri-urban areas.
- Advantages as low implementation cost and simplified Operation and Maintenance (O&M) are inadequately evaluated in the analyzed papers.
- The lack of specific laws and regulations about DEWATS and water reuse are barriers for expanding DW treatment.

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1. INTRODUCTION

Sanitation is currently one of the most difficult challenges in water management sustainability worldwide, and it will continue to be so in the coming years (Huang & Zhou 2021). Sewer sanitation services are linked to both water conservation and public health (Metcalf & Eddy 2016; Subtil et al. 2016; Marotti et al. 2017). The World Health Organization (WHO) considers a sewage sanitation service to be safe and adequate when sanitary appliances are not shared with people from a different household and domestic wastewater (DW) is either treated directly in the location where it was generated or is collected and sent to a proper treatment facility (WHO 2021a). According to the National Basic Sanitation Plan (Plansab – Plano Nacional de Saneamento Básico) in Brazil, an adequate sewage sanitation service includes collection, followed by treatment in a wastewater treatment facility, or the use of septic tank followed by a post-treatment (Brasil 2013).

Untreated DW disposal in water bodies is one of the most significant contributors to water quality deterioration, affecting the availability of this natural resource. Aside from water pollution, population growth, changes in people’s consumption patterns, and use of water sources beyond their sustainable limits, alongside the effects of climate change will have a significant impact on water availability, quantity, and quality. Thereby increasing the pressure on this natural resource and highlighting the need for sustainable water management that addresses conservation and efficient water use (Bates et al. 2008; Gikas & Tchobanoglous 2009; UNESCO UN-Water 2020).

As a result, proper DW collection and treatment are critical for ensuring the quality of both human health and the environment (Schwarzenbach et al. 2010; Metcalf & Eddy 2016). Furthermore, the importance of water quality maintenance is reinforced by the fact that among the United Nations (UN) Sustainable Development Goals (SDGs), universalization of access to drinking water and sewage sanitation services is linked directly or indirectly to other SDGs. These include for example, protection of life below water and on land, climate action, zero hunger, good health and well-being, and sustainable cities and communities (UN 2021).

In Brazil, the conditions and criteria for disposing of treated DW are established by Resolutions no. 357 and no. 430 of the National Environmental Council (CONAMA – Conselho Nacional do Meio Ambiente). Among the parameters used for...
qualifying direct discharge of treated DW in water bodies are pH, temperature, settleable solids, biological oxygen demand (BOD), oil and greases, and other 31 organic and inorganic elements (Brasil 2005; Brasil 2011).

1.1. Traditional wastewater treatment system and its development in Brazil

DW collection and treatment have traditionally been based on centralized systems in which the wastewater pipelines of a large urban and peri-urban area are unified, collected, and transported to large wastewater treatment facilities. This system requires a large pumping infrastructure, extensive pipelines, and a large amount of energy (Subtil et al. 2016; Capodaglio et al. 2017).

Centralized wastewater treatment facilities have become common in the world since the middle of the 19th century (Gikas & Tchobanoglous 2009). Sewer sanitation services in Brazil began in 1853, according to Azevedo Netto (1959), with a legislative act authorizing sewage services in the city of Rio de Janeiro. Between the years of 1857 and 1864, the city built its first sewage pipeline. The cities of Recife, São Paulo, and Santos built their first sewage pipelines in 1873, 1876, and 1889, respectively. In the year of 1892, the city of Campinas constructed its first sewage pipeline with septic tanks and percolating bed systems.

However, it was not until 1970, with the establishment of the National Sanitation Plan (Planasa – Plano Nacional de Saneamento) at the time and the establishment of 27 companies responsible for providing sanitation services to each Brazilian federal state, that access to sanitation services in the country was expanded (Sousa & Costa 2013; ABDIB 2021). Following that, the investments in basic sanitation declined considerably, with only a significant increase observed in 1990 (Saiani & Toneto Júnior 2010). Since 2007, when national law no. 11.445, known as the Sanitation Milestone, was enacted, financial investment in the sanitation sector has increased in general, reaching a peak in 2019. This year, approximately US$3.2 billion was invested, far exceeding the US$2.6 billion and US$2.2 billion invested in 2018 and 2017, respectively (Dutra et al. 2016; Brasil 2020a).

A new National Basic Sanitation Plan (Plansab) was approved in 2013, representing an important achievement for the sanitation sector as it is currently the main instrument of the national sanitation policy. It establishes short-, medium-, and long-term goals, aiming to achieve universal sanitation services over a 20-year period, from 2014 to 2033 (Brasil 2013). The commitment to universalization until 2033 was strengthened by national law no. 14.026 of 2020 (Brasil 2020b), which encourages private investment in the sanitation sector.

1.2. The need for new strategies

In 2019, the treatment index of all DWs generated in Brazil was 49.1% (Brasil 2020a), similar to what is observed on a global scale, where only 45% of the world’s population is estimated to have access to adequate and safe sanitation (The World Bank Group 2021; WHO 2021b). This current index falls short of the Plansab goal for the given time period, which predicted that by 2018, more than 50% of all generated DWs would be properly treated. In Brazil, there is significant disparity in the DW treatment index across the different regions of the country. The Center-West and Southeast regions have the best DW treatment indexes, treating more than 50% of all generated DWs, while the North and Northeast regions have the worst indexes, treating 22% and 33.7% of all the generated DWs, respectively. The parcel of DW that is not collected and/or treated is discharged directly into the soil or water bodies and contributes to the diffuse pollution of the areas (Brasil 2020a).

The current stage of sanitation services in Brazil demonstrates that the efforts and financial investments made since Plansasa, including legal regulation and planning, were ineffective in reducing the DW collection and treatment deficit. On the occasion of Plansab’s update in 2018, the optimistic reference scenario adopted by Plansab in 2013 was replaced with a more conservative scenario because the anticipated conditions did not materialize. The current target for 2033 is to treat 85.6% of all DWs generated in the country (Brasil 2020c).

Studies have shown that the sanitation service deficit, especially regarding DW collection and treatment, is concentrated in developing countries, rural areas, peri-urban areas, and informal settlements, such as slums (Massoud et al. 2009; Saiani & Toneto Júnior 2010; UNESCO WWAP 2019; UNICEF & WHO 2019; Brasil 2020a, 2020c). This demonstrates that, despite the critical role of centralized wastewater treatment systems, relying solely on them is unsuitable for the sustainable management of water resources. Therefore, adopting new strategies for increasing the coverage of sewage sanitation services is necessary (Gikas & Tchobanoglous 2009; Dutra et al. 2016; Capodaglio et al. 2017).

* Considering the average exchange rate for each given year: 2019 = R$3,9451/1 USD, 2018 = R$ 3,6542/1 USD; 2017 = R$ 3,1920/1 USD (Brazil 2021)
In general, DW centralized treatment facilities are financially appealing in areas where population and geographical characteristics favor economies of scale, because they require a significant initial capital investment and have high maintenance, operational, and management costs. The main costs in centralized DW treatment facilities are related to DW collection and transport infrastructures, which can account for up to 60% of total costs (Massoud et al. 2009; Von Sperling & Salazar 2013; Subtil et al. 2016).

Due to financial constraints in expanding sewage sanitation services, as well as the limited expansion capacity of centralized systems (Gikas & Tchobanoglous 2009; Dutra et al. 2016), new alternatives are being investigated. Among the actions and strategies described in Plansab for sanitation development is the consideration of options in which the technology used takes into account local and economic characteristics (Brasil 2013), features that correspond to decentralized systems.

1.3. DEWATS

In decentralized treatment systems, DW is collected, treated, and discharged (or reused) next to where it is generated (Maurer 2013; Subtil et al. 2016). The use of decentralized or alternative systems for DW treatment is predicted in rural or remote areas, as well as in urban informal settlements, as a strategy for achieving the universalization goals set forth in national law no. 14.026 (Brasil 2020b). However, no law or regulation in Brazil currently specifies the characteristics or conditions for a treatment facility to be considered a DEWATS.

Nevertheless, there is a definition for small DW treatment facilities. According to CONAMA Resolution no. 377, small DW treatment facilities have a project flow of 50 L/s or less and a capacity to serve up to 30,000 inhabitants (Brasil 2006), which are characteristics that most DEWATS have. Small DW treatment facilities have a streamlined process for obtaining the environmental permits for its functioning. According to data from the Brazilian Institute of Geography and Statistics (IBGE – Instituto Brasileiro de Geografia e Estatística), approximately 79% of Brazilian counties have a population of 30,000 inhabitants or less, demonstrating the enormous potential of small sewage treatment systems (Brasil 2020d).

DEWATS are versatile and can be used as a single-family DW treatment solution in remote areas, university campuses, commercial buildings, and industries, or as collective DW treatment solutions in clusters or satellite systems. In clusters/satellite systems, the DW generated by a group of people, usually inside a 5-km radius, is collected and directed to a treatment facility (Gikas & Tchobanoglous 2009; Subtil et al. 2016; Capodaglio et al. 2017).

The satellite organization of DEWATS tends to be more favorable in areas with a high density of people, like peri-urban areas. In such systems, a local DW pipeline collector is needed. Yet, the pipeline collector is smaller and less costly when compared to pipeline collectors of centralized treatment facilities (Massoud et al. 2009; Capodaglio et al. 2017). As, in DEWATS, DW treatment is done close to its point of generation, the costs of implementation, operation, and maintenance are considerably lower when compared to traditional centralized systems (Massoud et al. 2009; Larsen Tove et al. 2016; Capodaglio 2017; Jung et al. 2018).

Other features of DEWATS that are often mentioned as advantageous include: the possibility to install in response to current demand, preventing the underutilization of the installed capacity and thus reducing costs and increasing efficiency (Massoud et al. 2009; Maurer et al. 2010; Maurer 2013; Van Afferden et al. 2015; Larsen Tove et al. 2016); facilitation for resource recovery from DW (Maurer 2013; Tchobanoglous & Leverenz 2013); facilitation for water reuse, which contributes to reducing the demand for drinking water (Larsen Tove et al. 2016; Subtil et al. 2016; Capodaglio et al. 2017). All the aforementioned points have been regarded as a trend for the sewage sanitation sector, also known as New Sanitation, which represents more sustainable (waste)water management (Zeeman et al. 2008; Poortvliet et al. 2018; Wielemaker et al. 2018; Díaz-Elsayed et al. 2019).

Water reuse, including water recovered from DW, is one of the strategies mentioned in Plansab for achieving the goal of sanitation universalization, and it is encouraged by national law no. 14.026 (Brasil 2013, 2020b). However, there is currently no law or regulation governing the conditions and possibilities for treated DW water reuse. However, the Brazilian Technical Norm (NBR – Norma Brasileira) 13969 is used as a reference for water reuse. This norm addresses the design, construction, operation, and final disposition of DW treated by septic tanks followed by complementary treatment units (Brasil 1997). Nevertheless, it is worth noting that in May 2020, the Brazilian Chamber of Deputies approved the Law Project no. 2451/2020 on water reuse. The goal of this legislative project is to make water reuse mandatory in some Brazilian counties. Water sources anticipated in this law project include treated wastewater (both sanitary and industrial) and rainwater, with all predicted reuses being non-potable (Brasil 2020e).
DEWATS, like centralized treatment systems, must be carefully designed, operated, and maintained. In general, DW treatment facilities are designed to remove organic matter, suspended solids, pathogenic microorganisms, and nutrients in some cases (Leme 2010; Brasil 2017). The treatment process must be chosen considering the conditions established by law for treated DW discharge, as well as the characteristics of the water body that will receive the discharge, area availability, and economic, social, and operational aspects (Brasil 2017).

DEWATS treatment technologies range from simple technologies like septic tanks to more advanced technologies like membranes and nature-based technologies like the Constructed Wetlands (Massoud et al. 2009; Singh et al. 2015; Capodaglio et al. 2017; Lutterbeck et al. 2018; de Oliveira Cruz et al. 2019; de Souza Celente et al. 2019). According to data from the 2015 National Research by Household Sample (PNAD – Pesquisa Nacional por Amostra de Domicílios), 21.5% of the Brazilian population use a septic tank as a single-family DW treatment solution (Brasil 2015). However, it is important to note that the information displayed in the National System of Sanitation Information (SNIS – Sistema Nacional de Informações sobre Saneamento) is provided by sewage service provider companies. As a result, alternative or single-family treatment solutions are not accounted for in the national treatment index. These companies can be state companies, county autarchies, private companies, or even county authorities.

1.4. Current needs for dewats’ improvement

Despite the need to expand the current sewage sanitation service coverage and the potential of DEWATS, there are barriers to the use of new systems. Among these impediments, are the continuation of the business-as-usual attitude toward centralized treatment stations, the limited information about DEWATS performance, and the almost non-existent economic assessment of decentralized systems (Singh et al. 2015; Capodaglio et al. 2017). These issues, among others, are critical for the sustainability of sanitation systems. Recent research on global sanitation trends by Huang & Zhou (2021) reveals the sustainability of the systems, including wastewater treatment as one of the main subjects of study.

The proof of the effectiveness of a given treatment system is related to compliance with the conditions established by law for treated DW disposition and is essential for technology or a combination of technologies to be used on a large scale. The objectives of this study are to (a) identify DEWATS research done in Brazil over the last 20 years, (b) overview publications’ development and geographical region distribution in Brazil and verify their relationship to the main national sanitation legal milestones, (c) identify and discuss the technologies used as DEWATS and identify their methodological approaches, and (d) evaluate the potential use of DEWATS as part of the strategy for the universalization predicted by law considering operational and economic factors, as well as compliance with current national environmental regulations.

2. METHODS

A systematic review of the literature on DEWATS in Brazil was conducted to achieve the research objectives. As a result, Archival Research Methodology (ARM) was used, which is a strategy for inquiring about studies previously done (Searcy & Mentzer 2003). The description of this research methodology and its steps are presented below.

1. Defining database source: this review covered the well established scientific databases of Scopus, Science Direct, and Web of Science.
2. Delimitation of the scope: the timeframe covered was from 2001 to 2021, 18 March 2021 being the last date on which the database was screened for new papers.
3. Defining a unit of analysis: first, all search results were accepted.
4. Sampling: the sample of documents was defined by searching the following keywords in the mentioned databases: ‘decentralized wastewater,’ ‘decentralized waste water,’ and ‘decentralized sewage’.
5. Applying a regional filter: ‘Brazil’ as an affiliated country was used as a filter. Search results returned 193 results.
6. Conducting general compilation: a total of 111 articles were dismissed due to duplicity. Hence, the sample was reduced to 82 publications.
7. First screening: the title and abstract of each article were read to dismiss papers not related to the use of DEWATS. A total of 21 papers were dismissed; thus, the remaining sample comprised 61 papers.
8. Second screening: review papers, conference papers, and book chapters were dismissed. The number of dismissed papers was 10; thus, the remaining sample comprised 51 papers.
9. Third screening: all the remaining articles were read to confirm their relation to DEWATS. Six papers that presented no relation to DEWATS and/or were not performed in Brazil were dismissed. The final sample comprised 45 papers.

10. Defining final sample: the papers of the final sample were once again entirely read for the collection of data of interest.

The scheme of the process on which this review was based and its steps are shown in Figure 1.

A protocol for data collection was developed. The data of interest were those that provided general characteristics of each studied system, such as the technology investigated, the scale of the study, the year of publication, the type of effluent being treated, the intended area of application of the technology being investigated, the geographical region in which the study was performed, the operation data, the type of analysis performed in the study, the physical, chemical, and biological parameters evaluated, the intended or predicted water reuse, recovery of nutrients, system maintenance, economical assessment, and the use of the natural elements as part of the technology.

All data collected were organized and systematized in Microsoft Excel tables for further analysis. The CONAMA Resolutions no. 357 and no. 430 were chosen for comparison of the analysis’ results to the current Brazilian environmental law. These resolutions define water bodies classification based on their water quality and predominant use, as well as the standards and conditions for treated wastewater discharge.

3. RESULTS AND DISCUSSION

The content analysis and data interpretation from the final sample of 45 papers resulted in the evaluation of 47 studies about DEWATS conducted in Brazil over the last 20 years (two of the studies applied a comparative design and included two systems, respectively). First, the research done on DEWATS in Brazil over the last 20 years is presented. Second, an overview of the publications is done regarding the publications’ development through the years and their geographical region distribution alongside their relationship to the main national sanitation milestones. Third, the technologies used as DEWATS are identified and discussed, and the publications’ methodological approaches are identified. Finally, the potential use of DEWATS as part of the strategy for sanitation universalization is assessed in terms of operational, maintenance, and economic aspects, as well as compliance with the current national laws and regulations.

3.1. Research on DEWATS in Brazil

In the last 20 years, 45 publications regarding DEWATS in Brazil were identified. In Table 1, a summary of the studies and their main features is presented.

The studies were conducted utilizing three different types of effluents, as shown: DW, synthetic DW, and university campus sanitary wastewater. The performance of the systems/technologies was addressed in 38 of the studies. The remaining nine focused on specific topics, such as sludge volume reduction and digestion, the effect of endocrine disruptors exposure on fish, odor control in DEWATS, design tools, economic assessment, and the sustainability of DEWATS.

3.2. Overview of publications’ development and geographical region distribution

The distribution of papers about DEWATS over the last 20 years is presented in Table 2. It was observed that, over the two decades of publications examined for this review, publications about DEWATS have become more consistent beginning in 2018. The total number of papers published from 2018 to 2021 accounts for 60% of the time period under consideration. Given this, neither the Sanitation Milestone represented by the approval of national law no. 11.445 in 2007 nor the release of Plansab in 2013 resulted in an increase in the number of papers published about DEWATS. Nonetheless, there may be a link between financial investment in the sanitation sector and the number of DEWATS papers published, because the year with the most publications was also the year with the most money invested in the sector.

It is possible to conclude that interest in researching sanitation in Brazil increased over time and that, in general, this interest is quite recent, with the highest number of publications concentrated in the last 5 years, which follows the global trend of most publications concentrated in the last decade, indicating that sanitation research is on a growth stage (Huang & Zhou 2021).

In terms of the geographical region where the studies were conducted, one can see a concentration of research in both the Southeast and South regions, which account for more than 60% of the sample, as shown in Table 3.

One can observe that the number of publications about DEWATS is very low in the North and Northeast regions of Brazil, where DW treatment indexes have historically been very low. This highlights the critical importance of fostering research
aimed at identifying new alternatives and strategies, such as DEWATS, that consider local aspects and demands in order to improve the current sanitation situation in the aforementioned regions.
Table 1 | Summary of studies on decentralized wastewater systems in Brazil and their main features

| First Technology used in the treatment system | Type of Effluent | Post-Treatment | Application area | Performance analysis | Other topics mentioned | Authors |
|-----------------------------------------------|------------------|----------------|------------------|----------------------|------------------------|---------|
| AABR                                          | UC               | Disinfection   | Rural* pilot      | Yes                  | Water reuse           | Slompo & da Silva (2019) |
|                                               |                  |                |                  |                      | Ozone as disinfectant agent |                     |
|                                               |                  |                |                  |                      | Bamboo rings as medium in the anaerobic chamber | Silva et al. (2017a) |
|                                               |                  |                |                  |                      | Economic evaluation | Silva et al. (2017b) |
| Activated Sludge                              | Side-Stream Reactor | Synthetic | NS pilot | No | Reduction of sludge volume | Habermacher et al. (2015) |
| Extended Aeration                            | UC               | Disinfection   | Rural full       | Yes                  | Water reuse           | Albornoz et al. (2020)  |
|                                               |                  |                |                  |                      | Impact of rainwater on treatment |                     |
| SBR                                           | Domestic         | Constructed Wetland | NS pilot | Yes | System maintenance Nutrients Recovery | Baldovi et al. (2021) |
|                                               |                  |                |                  |                      | Biomass characterization | Fernandes et al. (2014) |
|                                               |                  |                |                  |                      | Biomass characterization | Fernandes et al. (2013) |
|                                               |                  |                |                  |                      | –                       | Fernandes et al. (2016) |
|                                               |                  |                |                  |                      | Estrogenic hormones analysis | Teixeira et al. (2018) |
| Anaerobic Reactor                            | Domestic         | Biomembrane Filter | Urban pilot | Yes | Quantification of gas production | Chimcuca et al. (2020) |
| Biodigester                                   | UC               | Microalgae + Constructed Wetland | Rural pilot | Yes | Water reuse | De Souza Celente et al. (2019) |
|                                               |                  |                |                  |                      | Impact in water quality of water body that receives the effluent | Lanna et al. (2019) |
|                                               |                  |                | Urban pilot | Yes | Water reuse Nutrients recovery | Dell’Ostel et al. (2020) |
| Constructed Wetland                          | Domestic         | –              | NS NS pilot      | No | LCA tool applied to constructed wetland assessment | Castañer et al. (2020) |
|                                               |                  |                |                  |                      | Assessment tool for design | Fioreze & Mancuso (2019) |
| Evapotranspiration Tank                      | Domestic         | –              | NS pilot         | Yes | Economic evaluation | Silva et al. (2017a) |
|                                               |                  |                |                  |                      | Nutrients recovery | Paulo et al. (2019) |
| Filter(s)                                     | Anaerobic and Sand | Domestic | –              | NS Pilot Yes | – | | Sanchez et al. (2018) |
|                                               | Anaerobic        | Constructed Wetland | Rural | NS Yes | Water Reuse Bamboo rings as medium in the anaerobic filter | Leonel et al. (2016) |
|                                               |                  |                |                  |                      | Use of coconut husks as medium in Anaerobic filter | Tonon et al. (2015) |
|                                               |                  |                |                  |                      | Use of coconut husks as medium in Anaerobic filter | Silva et al. (2015) |
|                                               |                  |                |                  |                      | Use of coconut husks as medium in Anaerobic filter | De Oliveira Cruz et al. (2013) |

(Continued.)
| First Technology used in the treatment system | Type of Effluent | Post-Treatment | Application area | Scale | Performance analysis | Other topics mentioned | Authors |
|---------------------------------------------|-----------------|----------------|------------------|-------|----------------------|------------------------|---------|
| Septic Tank                                 | Domestic        | Sand Filter    | Rural            | Full  | Yes                  | System maintenance     | De Oliveira Cruz et al. (2018) |
|                                             |                 | Anaerobic Filter + Sand Filter | Rural | Full | Yes | System maintenance, Water Reuse | Sousa et al. (2020) |
|                                             |                 | Constructed Wetland | NS | Full | Yes | Use of coconut husks as medium in Ana Filter | Decezaro et al. (2018) |
|                                             |                 | Aerated Filter + Constructed Wetland + Microalgae + Constructed Wetland | Rural | Full | Yes | – | Resende et al. (2019) |
|                                             |                 | Aerated Filter + Biofilter + Constructed Wetland + Microalgae + Sand Filter UASB | NS | Full | No | System maintenance, Water Reuse | Forgiarini & Rizzii (2016) |
|                                             |                 | UASB Anaerobic Filter + Sand Filter | NS | NS | No | Water Reuse | Duarte et al. (2019) |
|                                             |                 | Synthetic Microalgae | Rural | NS | Yes | Water Reuse | Slompo et al. (2020) |
|                                             |                 | Domestic Submerged Aerated Filter | Rural | Pilot | Yes | Nutrients Recovery, Nutrients Recovery | Slompo et al. (2019) |
|                                             |                 | Anaerobic Filter + Sand Filter | Rural | Full | Yes | System maintenance, Water Reuse | Ribeiro & Silva (2018) |
|                                             |                 | Anaerobic biobiofilter + Constructed Wetlands + UV Disinfection | Rural | Full | Yes | System maintenance, Water Reuse | Sousa et al. (2020) |
|                                             |                 | Sponge Bed Trickling Filter | NS | Full | Yes | Gas treatment | Ribeiro et al. (2017) |
|                                             |                 | Aerated Filter + Microalgae + Constructed Wetland | Urban | Pilot | Yes | – | Amaral et al. (2019) |
|                                             |                 | – | – | – | No | Chlorine and peracetic acid application for odor control and disinfection in DEWATS | Freitas et al. (2021) |

AABR, anaerobic/aerobic baffled reactor; LCA, life cycle analysis; SBR, sequencing batch reactor; Synthetic, synthetic domestic wastewater; NS, not specified; UASB, upflow anaerobic sludge blanked; UC, sanitary wastewater from university campus.

*Implied.
Given that in Brazil all regions have a low percentage of generated DW treatment, the search for solutions that collaborate to increase sanitation attendance levels is applicable across the entire country. In general, given the bold goal established in the National Sanitation Plan (Plansab) for 2033 and the need already identified by Gikas & Tchobanoglous (2009), Dutra et al. (2016), and Capodaglio (2017) for new sanitation expansion strategies, the number of Brazilian publications on DEWATS is low.

3.3. Technologies used as DEWATS and studies’ methodological approaches

As presented in Table 1, many technologies used as DEWATS were observed alongside various arrangements of units utilized for DW treatment, confirming the flexibility of DEWATS as highlighted by Capodaglio et al. (2017), Subtil et al. (2016), and Gikas & Tchobanoglous (2009). Septic Tank, in conjunction with post-treatment units, were the most used treatment technology. Septic tanks were used in 11 of the 38 studies in which some performance analyses were evaluated, representing 23.4% of the sample. Activated Sludge and UASB reactors, whether combined or not with post-treatment units, were used in eight studies each, representing 17% of the sample. These three treatment technologies together represent almost 60% of the studies analyzed. They are also among the most utilized treatment technologies in Brazil’s centralized treatment systems (Brasil 2017), demonstrating the application potential of well consolidated treatment systems on a smaller scale.

According to Singh et al. (2015), proof efficacy through scientific assessment is an important aspect to consider for the application possibility of new or existing technologies in new contexts. Based on the information presented in Table 1 and summarized in Figure 2, it is possible to confirm that most of the studies published about DEWATS included some type of performance analyses of the technology under consideration.

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**Table 2** Distribution of the number of publications from 2001 to 2021

| Year       | Publications |
|------------|--------------|
| 2001–2011  | 2            |
| 2012–2015  | 8            |
| 2016       | 4            |
| 2017       | 4            |
| 2018       | 8            |
| 2019       | 11           |
| 2020       | 6            |
| 2021       | 2            |

**Table 3** Distribution of studies, current wastewater treatment index, and wastewater treatment index goal for 2033 for each geographical region in Brazil

| Region     | DW treated concerning total generation $^a$ percentage | DW treated concerning total generation – Goal of Plansab for 2033 $^b$ percentage | Papers about DEWATS analyzed $^c$ quantity |
|------------|------------------------------------------------------|---------------------------------------------------------------------------------|------------------------------------------|
| North      | 22.0                                                 | 81.8                                                                            | 0                                        |
| Northeast  | 33.7                                                 | 79.1                                                                            | 5                                        |
| Southeast  | 55.5                                                 | 86.4                                                                            | 20                                       |
| South      | 47.0                                                 | 93.1                                                                            | 9                                        |
| Center West| 56.8                                                 | 80.6                                                                            | 1                                        |
| BRASIL     | 49.1                                                 | 85.6                                                                            | 45                                       |

$^a$SNIS (2020)—data from 2019.

$^b$BRASIL (2020a).

$^c$In 10 papers, it was not possible to identify the city nor the State in which the study was done (22.2% of the sample).
Overall, half of the studies applying a performance analysis were carried out in full-scale systems. However, this represents a small quantity in absolute terms, mainly when considering the low variety of technologies studied. This emphasizes that a gap remains for the efficacy of the desired technologies to be proven and its application as a DEWATS to be disseminated.

Once again, the prevalence of publications involving Septic Tank, UASB reactors, and Activated Sludge can be seen in all scales. However, it should be noted that the technologies mentioned in Figure 2 refer to the first element of the studied systems, and that many of the studies evaluated systems with more than one technology/element, as shown in both Table 1 and Figure 3.

From the final sample of 47 studies, 19 investigated systems with only one treatment technology, 16 systems with two technologies combined (main technology + post-treatment), four studies with three different technologies combined (main technology + 2 post-treatments), and four studies with four or more technologies combined. Constructed Wetlands were used as post-treatment for various technologies as well as the main treatment, demonstrating a strong interest in implementing low-cost systems with simplified operation and maintenance. Furthermore, the use of Microalgae as a post-treatment stage in Brazil indicates a trend toward resource reclamation.

3.4. Potential use of dewats

Many parameters were evaluated in the 38 studies that included some performance analyses. The parameters ranged from simple measurements, such as pH, to more complex measurements, such as the quantification of helminth eggs and estrogen hormones. The relation between all evaluated parameters and the number of times each was tracked is shown in Figure 4. None of the studies evaluated all the main parameters outlined in CONAMA Resolutions no. 357 and no. 430 (pH, temperature, settable solids, BOD, and oil and greases). Thus, although many important parameters were evaluated, the proposed systems’ compliance with environmental legal requirements could not be proven. Therefore, despite the use of DEWATS being predicted by the national law no. 14.026 signed in 2020, it is possible to conclude that implementing DEWATS on a large scale as part of the solution for sewage sanitation universalization remains a distant reality for Brazil.

As revealed by many authors, DEWATS facilitates water and nutrient reclamation from wastewater (Maurer 2013; Tchobanoglous & Leverenz 2013; Larsen Tove et al. 2016; SUBTIL et al. 2016; Capodaglio et al. 2017; Slompo et al. 2020). Both topics are part of the New Sanitation concept, in which sanitation systems are designed to recover, among other things, resources such as nutrients, and to minimize potable water use (Zeeman et al. 2008; Poortvliet et al. 2018; Wielemaker et al. 2018), strategies that Larsen Tove et al. (2016) identified as critical to achieving sustainable (waste)
water management. In this regard, it is possible to argue that treating DW only is outdated. As a result, the topics mentioned above were addressed in the final sample of 45 papers, as shown in Table 1 and as a compilation in Table 4. Aside from these topics, mentions of system maintenance and economic assessments were also observed, all of which were deemed relevant to the application potential of the studied systems.

Furthermore, the studies that were included highlighted the incorporation of natural elements in the systems/technologies. This contributes to the sustainable aspect of DW management and can have an impact on cost reduction. When compared to traditional centralized systems, the lower cost of DEWATS is frequently mentioned as an advantage in previous literature.
However, in the sample of publications analyzed in this review, only Resende et al. (2019) presented a general cost composition of the proposed technology, and Silva et al. (2017a) presented a comparison of the monthly electricity costs of a pilot system comprising an AABR reactor and Constructed Wetland attending 20 inhabitants with a conventional electric shower.

Regarding systems maintenance, Salomão et al. (2012), Forgiarini & Rizzi (2016), and Baldovi et al. (2021) conducted their research utilizing Constructed Wetlands as one technological element of the treatment systems and covered macrophytes maintenance. Additionally, Salomão et al. (2012) evaluated the general efficiency for pollutant removal of a robust full-scale treatment system combining Septic Tank, Aerated Filter, Constructed Wetland, and Microalgae, whereas Forgiarini & Rizzi (2016) investigated the efficiency of a full-scale system combining Septic Tank and Constructed Wetland attending a four people single-family for organic matter removal. Baldovi et al. (2021) investigated the effect of hydraulic retention time and seasonality on phosphorus removal in a pilot system of SBR and free surface Constructed Wetland.

Sousa et al. (2020) investigated two different systems, both of which included a sand filter as a technological component (UASB reactor + Anaerobic Filter + Sand filter and Septic Tank + Sand Filter). The authors de Oliveira Cruz et al. (2018, 2019) also used a sand filter in their systems. All mentioned authors conducted their studies on full-scale systems, serving a range from 3 to 15 people, and addressed basic maintenance of the sand filter regarding its cleaning.

Ribeiro & Silva (2018) monitored the operation of a full-scale compact treatment station equipped with a UASB reactor and a Submerged Aerated Filter. The system under consideration can serve a population of up to 1,709 people and treat 240 m³/day. They reported on the system’s maintenance in general, mentioning basic aspects such as the importance of regular equipment inspections for verifying the need for maintenance, the effects of operating with a flow greater than project flow, filter cleaning, and sludge discharge from a UASB reactor.

Considering all the information presented, it is clear that, despite being frequently mentioned, the economic advantage of DEWATS has not been thoroughly explored and evaluated in the studies examined. The same is true for systems maintenance, which is restricted to sand filters and macrophytes in Constructed Wetland maintenance.

Although DEWATS present features that facilitate water and other resource reclamation when compared to centralized systems, the topics were poorly explored by the publications examined. Thus, these facts are relevant as water and resource reclamation are part of the characteristics that make DEWATS appealing and contribute to sustainable water management. Aside from that, these features can be investigated economically for reduction of operation and maintenance costs.

Concerning resource reclamation from DW, only nutrient recovery was addressed in the publications reviewed, with the nutrients phosphorus (P) and nitrogen (N) being the nutrients in question. Slompo et al. (2019) evaluated N and P content in DW treated using a UASB reactor and mentioned their reclamation potential by, for example, Microalgae; Dell’Osbel et al. (2020) investigated the absorption of N and P by the plants in a Constructed Wetland used as a Biodegestor post-treatment and identified the potential use of the plants as biomass for nutrient cycling in future studies; Paulo et al. (2019) discuss nutrients absorption by the plants used in an Evapotranspiration Tank and the potential for reclamation.

Slompo et al. (2020) went one step further and used a Microalgae photo-bioreactor as a UASB reactor post-treatment, demonstrating the potential of the method for N and P absorption for biomass production; Baldovi et al. (2021) investigated the absorption of P by the plants used in a Constructed Wetland as post-treatment of an SBR and estimated corn production based on the amount of P reclaimed by the biomass.

Water reuse was the most mentioned topics of interest in this review. The predicted or intended water reuse indicated in the publications is shown in Table 5.

Table 5 | Topics of interest about decentralized systems and the number of studies in which they were mentioned

| Topic                                           | Quantity | %   |
|-------------------------------------------------|----------|-----|
| Water reuse                                     | 11       | 24  |
| Nutrients’ recovery                             | 5        | 11  |
| Aspects of system maintenance                   | 7        | 16  |
| Perform some sort of economic evaluation         | 2        | 4   |
| Incorporation of natural elements in the proposed technology | 7 | 16 |

Since most of the studies that addressed water reclamation predicted that the system would be used in rural areas, agricultural water reuse, which is the use with fewer quality requirements according to NBR 13969 (Brasil 1997), is the most
intended application. The lack of a national law or specific technical standard regarding the reutilization of water obtained through DW treatment may be a limiting factor for the development of research and further exploitation of the DEWATS topic. However, water reuse is a topic that has received growing attention in recent years.

In general, it can be asserted that the main advantages associated with DEWATS were not thoroughly explored in the analyzed publications. As the use of DEWATS is predicted by law and is part of the National Basic Sanitation Plan (Plansab), it is necessary to investigate their alleged benefits the most possibly for verifying whether these advantages apply to the Brazilian context and the technical, economic, and social principles necessary for its implementation.

Another important factor to consider is the scale on which the studies were conducted as the performance evaluation of the systems should be done in real situations or in the closest possible situation to its intended use. Thirty-six publications conducted some performance analyses, evaluating 38 different treatment systems. About half the studies were conducted on a full scale, and the relation of these studies is presented in Table 6.

In all the studies conducted in full-scale, the operational or projected flow was less than 50 L/s or 4,320 m³/day; thus, all can be classified as small treatment facilities according to CONAMA Resolution no. 377 (Brasil 2006), which can be implemented for serving up to 30,000 people and thus be a potential option for 79% of Brazilian counties (Brasil 2020d). Considering this, the enormous potential applicability of DEWATS as a tool for improving sanitation in Brazil is clarified.

It is possible to see that there are more studies in which DEWATS are proposed as a collective solution for DW treatment than as single-family solution. Collective systems fit the definition of satellite systems, which are interesting for presenting certain economies of scale, also, single-family treatment solutions are not considered by the National System of Sanitation Information (SNIS).

Given that the use of DEWATS or alternative DW treatment systems is part of the national strategy for sanitation universalization, there is a need for data collection and mapping of DEWATS for their inclusion in the SNIS, as it is contradictory to encourage the adoption of such systems if the amount of DW treated by them is not accounted for tracking the progress of wastewater treatment index toward reaching the defined goals.

A predominance of studies aimed at applying DEWATS in rural areas. One of the key findings was that the studies in general chose to use already consolidated technologies that, in theory, require less maintenance and specialized human resources and have a simpler operation. Nevertheless, the low DW treatment index is not limited to rural areas; it is also a problem in urban areas, particularly in poor areas such as slums and in irregular occupations established outside of counties guidelines. Therefore, the search for sanitation alternative solutions that can be used in urban areas with high population density and few available areas is substantiated in Brazil.

The use of more recent DW treatment technologies that work with high rates, such as membranes or a moving bed biofilm reactor (MBBR) was of interest in the analyzed studies. This occurrence is thought to be related to the filter used to select the papers and to the disconnection between the research and their potential use as DEWATS.

Other topics not covered in the papers included the energy reclamation from anaerobic systems’ biogas and the disposal of sludge generated in DEWATS. Because of the potential operational cost savings, energy reclamation from anaerobic systems’

| Predicted or intended reuse | Quantity of publications | Authors | Intended area of application |
|----------------------------|-------------------------|---------|-----------------------------|
| Agriculture                | 7                       | De Oliveira Cruz et al. (2018) | Rural |
|                            |                         | De Oliveira Cruz et al. (2019) | Rural |
|                            |                         | Albornoz et al. (2020)         | Rural |
|                            |                         | Slompo & da Silva (2019)       | Rural |
|                            |                         | Slompo et al. (2020)           | Rural |
|                            |                         | Sousa et al. (2020)            | Rural |
|                            |                         | Leonel et al. (2016)           | Rural |
| Plants’ watering/Floor washing/Landscaping | 2 | De Souza Celente et al. (2019) | Rural |
|                            |                         | Dell’Osbel et al. (2020)       | Urban |
| Concrete production        | 1                       | Duarte et al. (2019)           | NS |
| Car washing/Fountains/Toilet flushing | 1 | Dell’Osbel et al. (2020)       | Urban |
| Not Specified              | 1                       | Lutterbeck et al. (2018)       | Rural |

NS, Not Specified.
biogas may be an important factor in the viability of DEWATS. Sludge management is important because of the costs of its proper disposal as well as the potential negative effects on human health and the environment from improper handling and disposal. It is important to mention that sanitation is inter- and multidisciplinary, involving many research fields and subjects (Huang & Zhou 2021); thus, the sampling criteria used for this review do not cover all topics.

4. CONCLUSIONS

Through a systematic review based on ARM, 45 papers about DEWATS in Brazil over a 20-year period were identified. It was observed that the interest in the topic is relatively new, as most of the papers were published within the last five years. No evidence was found suggesting that the approval of the main sanitation legal frameworks in Brazil influenced the number

| Wastewater | System used for treatment | Area of application | System used by | Authors | Population attended | Project Q or Treated Q (m³/day) |
|------------|---------------------------|---------------------|----------------|---------|---------------------|-------------------------------|
| Domestic   | Biodigester               | Rural               | Single-family  | Lanna et al. (2019) | 78 dwellings | – |
| UC         | Activated Sludge + Disinfection | Rural           | University Campus | Albornoz et al. (2020) | ~550 people | 91** |
| Domestic   | Activated Sludge (SBR)    | Urban               | Collective     | Fernandes et al. (2014) | – | 168 |
|            |                           |                     | Collective     | Fernandes et al. (2013) | – | – |
|            |                           | NS                  | Collective     | Fernandes et al. (2016) | – | 52,36 |
| UC         | Activated Sludge (SBR)    | NS                  | University Campus | Teixeira et al. (2018) | – | 85 |
| Domestic   | Evapotranspiration        | Rural*              | Single-family  | Paulo et al. (2019) | 2 people | – |
| Domestic   | Septic Tank + Sand Filter | Rural               | Collective     | De Oliveira Cruz et al. (2018) | 8-10 people | 0,717 |
|            |                           |                     |                | Sousa et al. (2020) | 15 people | 1,5 |
|            | Septic Tank + Sand Filter + Anaerobic Filter | Rural         | Collective     | De Oliveira Cruz et al. (2019) | 8-10 people | 0,29 |
|            | Septic Tank + Constructed Wetland | NS         | Collective     | Decezar et al. (2018) | 10 people | 1,5 |
| Domestic   | UASB + Aerated Filter     | NS                  | Collective     | Forgiarini & Rizzi (2016) | 4 people | 0,52 |
|            |                           |                     |                | Salomão et al. (2012) | 12-16 people | 1,248 |
| Domestic   | UASB + Sand Filter + Anaerobic Filter | Rural      | Single-family  | Sousa et al. (2020) | 3 people | 0,3 |
| Domestic   | UASB + Anaerobic Filter + Constructed Wetland + UV Disinfection | Rural      | Single-family  | Lutterbeck et al. (2018) | 4-6 people | – |
| Domestic   | UASB + Sponge-Bed Trickling Filter | NS       | Collective     | Ribeiro et al. (2017) | 500 people | 45,7 |
| UC         | UASB                      | NS                  | University Campus | Amaral et al. (2019) | 1,582 people | 204 |

UC, sanitary wastewater from University Campus; NS, Not Specified.
*Implied.
**Estimated by adopting contribution of 130 L per person (NBR 7229/93—Brazilian Technical Norm). (Brasil 1993).
of papers published. The number of publications, conversely, can be linked to financial investment in the sanitation sector because the year with the highest number of published papers was also the year with the most financial support for the sanitation sector.

The variety of technologies investigated as DEWATS, as well as the large variety of elements that comprised the systems, demonstrate the flexibility of decentralized systems. Nevertheless, the use of Septic Tank, Activated Sludge, and UASB reactors stands out, highlighting the potential use of conventional and widely used centralized DW treatment technologies in Brazil on a small scale. Still, regarding the technological aspect, in the papers examined, high-rate technologies were not studied. In general, the studies conducted were limited to simpler technologies.

Most of the papers examined referred to investigating rural sanitation alternatives. Although the rural sanitation deficit must be addressed and expanding DW treatment in these areas contributes to improving the treatment index in Brazil, the lack of sanitation is not restricted to rural areas. There is a need for DEWATS studies that can address urban and peri-urban areas with a high population density and adversities that limit this population’s access to conventional centralized treatment systems.

Around half of the papers investigated systems that combined two or more treatment technologies. Some performance analyses were carried out in 81% of the final sample studies. However, none of those studies evaluated all the main quality parameters defined by the national environmental regulation (CONAMA Resolutions no. 357 and no. 430) in which the characteristics of treated wastewater and the conditions for its disposal are defined. As a result, it was not possible to determine whether the proposed systems would comply with the current regulations if used as an alternative to centralized systems.

In terms of the practical aspects of DEWATS, although frequently mentioned, the advantages of low implementation and maintenance costs, as well as simplified operations, were underappreciated in the papers reviewed. Hence, it was not possible to attest to these advantages.

Nutrients’ recovery and reuse of the DW treated by DEWATS were investigated in 11 and 24%, respectively. Concerning nutrient recovery, research was restricted to phosphorus and nitrogen. Energy reclamation through biogas from anaerobic reactors was not assessed when such treatment technologies were investigated.

For the reuse of treated DW, most of the papers in which the topic was explored predicted the treatment systems to be used in rural areas; thus, agricultural reuse was the most mentioned application of the treated DW. It is worth noting that agricultural reuse has fewer quality restrictions than other possible applications, such as car washing and toilet flushing. The lack of specific regulations governing the reuse of treated DW may be a limiting factor for the development of research in the context of DEWATS. In any case, it is worth noting that, of the topics of interest assessed in the papers sample, reuse was the most explored. This draws attention to the interest in exploring this advantage of DEWATS.

The management of the sludge generated in DEWATS was not addressed in any of the papers. This topic is imperative due to the health and environmental risks associated with inadequate handling and disposal of the sludge. Yet, as the sludge from DW systems is a solid residue, research on its handling and management may be published dissociated from DEWATS, thereby impairing a fully sustainable approach for this alternative.

From the legal point of view, there are also gaps to be filled, such as the parameters and definitions that govern the characteristics of a DEWATS, as well as strategies for mapping and data collecting of DEWATS for their inclusion in the SNIS, thus being accounted for the national DW treatment index.

Around half of the publications in which some performance analyses were evaluated were conducted in full-scale studies. This is important regarding the evaluation of the potential of systems’ applicability. All of these studies worked with a flow rate within the range defined for small treatment stations, having the potential to attend 79% of the Brazilian counties.

As the use of DEWATS is predicted by law and is part of the National Sanitation Plan (PLANSAB – Plano Nacional de Saneamento Básico) for universalization of sanitation in Brazil, and considering the papers published in the last 20 years and their content, it can be concluded that there are many aspects requiring thorough investigation for testifying compliance to the Brazilian environmental regulations, reliability of the systems costs estimation, and maintenance and optimal operational conditions. Therefore, despite the increase in the number of papers published in recent years, DEWATS still have a long way to go before they can be considered a viable alternative to centralized DW treatment systems.

DATA AVAILABILITY STATEMENT

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

Albornoz, L. L., Centurião, T. C., Giacobbo, A., Zoppas-Ferreira, J. & Bernardes, A. M. 2020 Influence of rain events on the efficiency of a compact wastewater treatment plant: a case study on a university campus aiming water reuse for agriculture. *Environmental Science and Pollution Research* 27 (33), 41350–41360. doi:10.1007/s11356-020-10102-w.

Amaral, S. R., Dos Santos, L. V., Lima, L. M., Vich, D. V. & Queiroz, L. M. 2019 A modified upflow anaerobic sludge blanket reactor as an alternative for decentralized domestic wastewater treatment in developing countries. *Water Practice and Technology* 14 (2), 249–258. doi:10.2166/wpt.2019.009.

Associação Brasileira da Infraestrutura e Indústrias de Base (ABDID) 2021 Dez anos da lei de saneamento: legado e perspectivas. Seminário “As soluções para o saneamento básico e os recursos hídricos no Brasil (Ten Years of the Sanitation law: Legacy and Perspectives. *Seminar The Solutions for Basic Sanitation E Water Resources in Brazil*). Available from: https://www.abdib.org.br/wp-content/uploads/2017/03/Analise-legado-Lei-11445.pdf (accessed 22 May 2021).

Azevedo Netto, J. M. 1995 Cronologia dos Serviços de Esgotos, com especial menção ao Brasil (Chronology of sewage services with special mention to Brazil). *Revista DAE* 33 (704), 15–19.

Baldovi, A. A., de Barros Aguiar, A. R., Benassi, R. F., Vymazal, J. & de Jesus, T. A. 2021 Phosphorus removal in a pilot scale free water surface constructed wetland: hydraulic retention time, seasonality and standing stock evaluation. *Chemosphere* 266. doi:10.1016/j.chemosphere.2020.128939.

Bates, B. C., Kundzewicz, Z. W., Wu, S. & Palutikof, J. P. 2008 *Climate Change and Water*. In: *Technical Paper of the Intergovernmental Panel on Climate Change*. IPCC Secretariat, Geneva, Switzerland, p. 210. doi:10.1029/90EO00112.

Braga, A. F. M., Pereira, M. B. O. C., Zaïat, M., da Silva, G. H. R. & Fermoso, F. G. 2018 Screening of trace metal supplementation for black water anaerobic digestion. *Environmental Technology (United Kingdom)* 39 (14), 1776–1785. doi:10.1080/09593330.2017.1340343.

Brasil. Agência Nacional de Águas (ANA) 2017 Atlas Esgotos: Despoluição de bacias hidrográficas/Agência Nacional das Águas, Secretaria Nacional de Saneamento Ambiental (Sewage Atlas: Depollution of Watersheds/Water National Agency, National Secretariat of Environmental Sanitation), Brasília: ANA, Brazil.

Brasil. Associação Brasileira de Normas Técnicas (ABNT) 1993 NBR 7229: Projeto, construção e operação de sistemas de tanques sépticos (Brazilian Norm N.7229: Design, Construction, and Operation of Septic Tanks’ Systems). Rio de Janeiro, Brazil, p. 15.

Brasil. Associação Brasileira de Normas Técnicas (ABNT) 1997 NBR 13969: Tanques sépticos – Unidades de tratamento complementar e disposição final dos efluentes líquidos – Projeto, construção e operação (Brazilian Norm N.13969: Septic Tanks – Complementary Treatment Units and Final Disposal of Liquid Effluents – Design, Construction, and Operation). Rio de Janeiro, Brazil, p. 60.

Brasil. Câmara dos Deputados 2020c Projeto de Lei nº 2451 de 6 de maio de 2020 (Law Project N. 24516 May 2020). Brasília, Brazil. Available from: https://www.camara.leg.br/proposicoesWeb/chadetramitacao?idProposicao=2251907 (accessed 11 May 2020).

Brasil. Instituto Brasileiro de Geografia e Estatística (IBGE) 2020d *Estimativas da População Residente Para os Municípios E Para as Unidades da Federação Brasileiros com Data de Referência em 1° de Julho de 2020 (Estimative of Resident Inhabitants for Counties and Brazilian Federal Units with Reference Data of 1st of July 2020)*. Available from: https://www.ibge.gov.br/estatisticas/sociais/populacao/9109-projecao-da-populacao.html?–t&l=– (accessed 5 May 2021).

Brasil. Instituto Brasileiro de Geografia e Estatística (IBGE) 2015 PNAD – Pesquisa Nacional por Amostra de Domicílios 2015: Domicílios Particulares Permanentes, Tipo de Esgotamento Sanitário, Tamanho e Localização. *National Research by Household Sample 2015: Private Permanent Households, Kind of Sewage System*. Available from: https://cidades.ibge.gov.br/brasil/pesquisa/44/47044 (accessed 5 May 2021).

Brasil. Instituto de Pesquisa Econômica Aplicada 2021 Taxa de câmbio comercial para venda: real (R$)/american dólar (US$) – média (Commercial Exchange rate for selling: real (R$)/american dollar (US$) – average). Available from: http://www.ipeadata.gov.br/ExibeSerie.aspx?serid=31924 (accessed 27 March 2021).

Brasil. Ministério das Cidades. Secretaria Nacional de Saneamento Básico 2013 *Plano Nacional de Saneamento Básico – PLANSAB (National Plan of Basic Sanitation – PLANSAB)*. Brasília, Brazil.

Brasil. Ministério do Desenvolvimento Regional. Secretaria Nacional de Saneamento. Sistema Nacional de Informações sobre Saneamento (SNIS) 2020a *Diagnóstico dos Serviços de Água e Esgoto 2019 (Diagnosis of Water and Sewage Services 2019)*. Secretaria Nacional de Saneamento, Brasília, Brazil.

Brasil. Ministério do Desenvolvimento Regional. Secretaria Nacional de Saneamento 2020c *Plano Nacional de Saneamento Básico (Plansab) – Relatório de Avaliação Anual 2018 (National Plano of Basic Sanitation (Plansab) – Annual Evaluation Report 2018)*. Brasília, Brazil.

Brasil. Ministério do Meio Ambiente. Conselho Nacional do Meio Ambiente (CONAMA) 2005 *Resolução nº 357, 18 de março de 2005 (Resolution n.357, 18 March 2005)*. In Diário Oficial [da União], Brasília, Brazil.

Brasil. Ministério do Meio Ambiente. Conselho Nacional do Meio Ambiente (CONAMA) 2006 *Resolução nº 377, de 9 de Outubro de 2006 (Resolution n. 377, 9 October 2006)*. In Diário Oficial [da União], Brasília, Brazil.

Brasil. Ministério do Meio Ambiente. Conselho Nacional do Meio Ambiente (CONAMA) 2011 *Resolução nº 430, de 13 de maio de 2011 (Resolution N. 430, 13 May 2011)*. In: Diário Oficial [da União], Brasília, Brazil.

Brasil. Secretaria-Geral 2020b *Lei nº 14.026 de 26 de julho de 2020 (Law N. 14026, 26 July 2020)*. Diário Oficial [da União], Brasília, Brazil.

Capodaglio, A. G. 2017 Integrated, decentralized wastewater management for resource recovery in rural and peri-urban areas. *Resources, Conservation & Recycling* 6 (22). doi:10.3390/resources6020022.
Jung, Y. T., Narayanan, N. C. & Cheng, Y. L. 2018 Cost comparison of centralized and decentralized wastewater management systems using optimization model. Journal of Environmental Management 215, 90–97. doi:10.1016/j.jenvman.2018.01.081.

Lanna, M. C. S., Viancelli, A., Michelson, W., Carvalho, S. V. C., Reis, D. A., Salles, L. A. F., Sant’Anna, I. H., Resende, L. T., Ferreira, C. S., Chagas, I. A., Hernández, M., Treichel, H., Rodríguez-Lázaro, D. & Fongaro, G. 2019 Household-based biodigesters promote reduction of enteric virus and bacteria In vulnerable and poverty rural areas. Environmental Pollution 252, 8–13. doi:10.1016/j.envpol.2019.05.104.

Larsen Tove, A., Hoffmann, S., Lüthi, C., Truffer, B. & Maurer, M. 2016 Emerging solutions to the water challenges of an urbanizing world. Science 352 (6288), 928–933. doi:10.1126/science.aad8641.

Leme, E. J. d. A. 2010 Manual Prático de Tratamento de Águas Residuárias. EdUFSCar, São Carlos, p. 595.

Leonel, L. P., Tonetti, A. L., Silva, J. C. P. da, Nunes, E. A. & Anaruma Filho, F. 2016 Reuse of sewage treated effluent in agricultural practices: an alarming presence of giardia spp. cysts. Ecological Engineering 94, 682–687. doi:10.1016/j.ecoleng.2016.06.126.

Lutterbeck, C. A., Zerwes, F. V., Radlke, J. F., Köhler, A., Kist, L. T. & Machado, E. L. 2018 Integrated system with constructed wetlands for the treatment of domestic wastewaters generated at a rural property – evaluation of general parameters ecotoxicity and cytogenetics. Ecological Engineering 115, 1–8. doi:10.1016/j.ecoleng.2018.01.004.

Marotti, A. C. B., Santiago, C. D. & Pugliesi, E. 2017 Aplicação de instrumento para avaliação de planos municipais de gestão integrada de resíduos sólidos ante às politicas públicas: estudo de caso do município de Rio Claro – SP (Application of tool for evaluation of counites’ integrated solid waste management plans in view of public policies: case study of Rio Claro county, São Paulo). Desenvolvimento E Meio Ambiente 41, 191–214. doi:10.5380/dma.v4i10.46020.

Massoud, M. A., Tarhini, A. & Nasr, J. A. 2009 Decentralized approaches to wastewater treatment and management: applicability in developing countries. Journal of Environmental Management 90 (1), 652–659. doi:10.1016/j.jenvman.2008.07.001.

Maurer, M. 2013 Full costs, (dis-)economies of scale and the price of uncertainty. In: Source Separation and Decentralization for Wastewater Management (Larsen, T. A., Udert, K. M. & Lienert, J. eds.). IWA Publishing, London, United Kingdom, pp. 85–100.

Maurer, M., Wolfram, M. & Anja, H. 2010 Factors affecting economies of scale in combined sewer systems. Water Science and Technology 62 (1), 36–41. doi:10.2126/wst.2010.241.

Metcalf & Eddy 2016 Tratamento de Efluentes E Recuperação de Recursos (Wastewater Engineering – Treatment and Resource Recovery); Translation: Ivanildo Hespanhol, José Carlos Mierzwa, 5th ed. AMGH, Porto Alegre.

Parkinson, J. & Tayler, K. 2003 Decentralized wastewater management in peri-urban areas in low-income countries. Environment and Urbanization 15 (1), 75–90. doi:10.1630/095624703101286556.

Paulo, P. L., Galbiati, A. F., Magalhães Filho, F. J. C., Bernardo, F. S., Carvalho, G. A. & Boncz, M. Á. 2019 Evapotranspiration tank for the treatment, disposal and resource recovery of blackwater. Resources, Conservation and Recycling 147, 61–66. doi:10.1016/j.resconrec.2019.04.025.

Pooortvliet, P. M., Sanders, L., Weijma, J. & De Vries, J. R. 2018 Acceptance of new sanitation: the role of end-users’ pro-environmental personal norms and risk and benefit perceptions. Water Research 131, 99–90. doi:10.1016/j.watres.2017.12.032.

Resende, J. D., Nolasco, M. A. & Pacca, S. A. 2019 Life cycle assessment and costing of wastewater treatment systems coupled to constructed wetlands. Resources, Conservation and Recycling 148, 170–177. doi:10.1016/j.resconrec.2019.04.034.

Ribeiro, J. C. & Silva, G. H. R. d. 2018 Acompanhamento operacional e avaliação de uma estação compacta de tratamento de esgoto sanitário: reator UASB seguido de filtro aerado submerso (Operational follow-up and evaluation of a compact domestic wastewater treatment station: UASB reactor followed by submerged aerated filter). Engenharia Sanitaria E Ambiental 23 (1), 27–31. doi:10.1590/s0104-06182010000100004.

Ribeiro, T. B., Brandt, E. M. F., de Almeida, P. G. S., Flórez, C. A. D. & Chernicharo, C. A. d. L. 2017 Technological improvements in compact UASB/SBTF systems for decentralized sewage treatment in developing countries. Desalination and Water Treatment 66 (10), 2131–2137. doi:10.2166/wst.2012.434.

Ribeiro, T. B., Brandt, E. M. F., de Almeida, P. G. S., Flórez, C. A. D. & Chernicharo, C. A. d. L. 2017 Technological improvements in compact UASB/SBTF systems for decentralized sewage treatment in developing countries. Desalination and Water Treatment 112, 120. doi:10.5004/dwt.2017.21611.

Saiani, C. C. S. & Toneto Júnior, R. 2010 Evolução do acesso a serviços de saneamento básico no Brasil - 1970 a 2004 (Evolution of access to basic sanitation services in Brazil from 1970 to 2004). Economia E Sociedade 19 (1), 79–106. doi:10.1590/s0104-06182010000100004.

Salomão, A. L. S. & Marques, M., 2015 Estrogenicity and genotoxicity detection in different contaminated waters. Human and Ecological Risk Assessment 21 (7), 1793–1809. doi:10.1080/10807039.2014.987027.

Salomão, A. L. S., Marques, M., Severo, R. G. & Roque, O. C. D. C. 2012 Engineered ecosystem for on-site wastewater treatment in tropical areas. Water Science and Technology 66 (10), 2131–2137. doi:10.2166/wst.2012.434.

Sanchez, A. A., Ferreira, A. C., Stopa, J. M., Jesus, T. A. d., Coelho, L. H. G., Domingues, M. R., Subtil, E. L., Matheus, D. R. & Benassi, R. F. 2018 Organic matter, turbidity, and apparent color removal in planted (Typha spp. and Eleocharis sp.) and unplanted constructed wetlands. Environmental Journal of Technology 144 (10). doi:10.1061/(asce)ee.1945-7787.0001443.

Santos, S. L., De Oliveira Simões, J. P., Paiva, F. V. & Van Haandel, A. 2017 Design optimization of a simple, single family, anaerobic sewage treatment system. Water Practice and Technology 12 (1), 55–71. doi:10.2166/wpt.2017.010.

Santos, S. L., Simões, J. P. d. O., Paiva, F. V. & Van Haandel, A. 2018 Projet de otimização de sistemas anaeróbios para tratamento de esgoto em escala unifamiliar (Optimization design of anaerobic systems for treating sewage at single-family scale). Engenharia Sanitaria E Ambiental 23 (6), 1213–1225. doi:10.1590/s1413-41522018166570.

Schwarzenbach, R. P., Egli, T., Hofstetter, T. B., von Gunten, U. & Wehrli, B. 2010 Global water pollution and human health. Annual Review of Environment and Resources 35, 109–136. doi:10.1146/annurev-environ-100809-125342.

Searcy, D. L. & Mentzer, J. T. 2003 A framework for conducting and evaluating research. Journal of Accounting Literature 22 (07374607), 130–167.
