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Review of technological alternatives for wastewater treatment in Brazilian rural areas

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Abstract— *Brazil and other Latin American countries face significant challenges in providing adequate sanitation to its rural residents, particularly concerning sewage treatment. The solutions implemented are often based on traditional knowledge, with cesspits and biodigester septic tanks being widely used, which may prove inadequate in many situations. These technologies require enhancement, and exploring additional alternatives, such as systems enabling the separation of toilet water from grey water, is imperative. In this context, the evapotranspiration tank emerges as a viable option due to its ability to prevent direct contact with influent sewage and its non-production of final effluent. While infiltration trenches also present a feasible solution, existing sizing recommendations typically overlook the unique demands of Brazilian rural areas by only considering the combined flow of grey water and toilet effluent. Moreover, the utilization of traditional septic tanks and anaerobic filters poses challenges, particularly concerning sludge management in isolated locations. Promising alternatives like vermifiltration and banana tree circles exist, yet their effective implementation require the establishment of standards for appropriate sizing. Therefore, although technologies are available to alleviate the sewage treatment deficit in rural regions, it is crucial to advocate for their informed selection among rural households and to bolster governmental efforts in implementing national legislation and refining standards and guidelines.*

Keywords— ***sanitation, treatment, sewage, decentralized, rural, single family treatment systems.***

I. INTRODUCTION

Rural sanitation in countries with vast territorial dimensions is characterized by inherent challenges arising from their extensive cultural, social, territorial, economic, and environmental diversity. Varied land use patterns, unequal distribution of water sources, traditional population characteristics and habits, as well as income disparities, contribute to the adoption of specific sanitation practices (Brazil, 2019).

Brazil exhibits these characteristics, and a recent report highlighted the significant challenge of rural sanitation particularly regarding sewage treatment (IBGE, 2019). Brazilian rural population totals nearly 30 million people, which is comparable to the entire population of countries like Peru, Venezuela or Poland.

In 2022, approximately 69.5% of Brazilians had access to sewage systems, either directly connected or through individual septic tanks linked to the public sewage network (IBGE, 2023). Conversely, 16.3% of Brazilians relied on septic tanks not connected to the public sewage network, while 14.1% of households, roughly totaling 10.4 million people, disposed their wastewater in cesspits, ditches, rivers, lakes, seas, or other forms of drainage. Among rural households only, 40.2% utilized septic tanks not connected to the public sewage system, while 50.5% resorted to other forms of wastewater disposal (IBGE, 2023).

Another challenge lies in the universalization of individual bathrooms in Brazilian households. While 99.4% of urban population has access to this amenity, the percentage drops to 89.7% in rural areas (IBGE, 2023). According to the Global Health Observatory Data Repository, 1% of the rural Brazilian population still practices open defecation (WHO, 2022). In many rural households, sanitation facilities are rudimentary, damp, malodourous, and lack proper structure. Consequently, due to the fear of the collapse of these structures and the consequent falling into pit latrines, residents opt for open defecation (Funasa, 2019). Another contributing factor to open defecation is the lack of access to piped drinking water. People refrain from using toilets with water-based sanitation facilities to conserve water for what they perceive as more "noble" purposes (Roland et al., 2019).

An important aspect that also intersects with the sanitation issue is gender. Women exposed to inadequate sanitation facilities often report discomfort and insecurity, due to the lack of privacy and fear of being surprised or even assaulted, as well as the difficulty of maintain proper hygiene (Roland et al., 2019).

While a large amount of the Brazilian rural households lacked access to sewage network, septic tanks, or discharged wastewater into ditches, in the soil, or in water bodies (IBGE, 2019), what happens with the remaining residences? How do they manage sewage? Before addressing the questions, we must understand how sanitation is organized in Brazilian rural areas. Only by establishing this foundation it will be able to comprehend the most common solutions adopted for sewage treatment.

Legal aspects

In Brazil, the sanitation deficit reflects the lack of investments and subsidies, as well as the delayed development of a national sanitation policy, which was only established in 2007 by the Federal Law 11,445/07 (Brazil, 2007), and updated in 2020 by Federal Law 14,026/20 (Brazil, 2020). This legislation stipulates that the government is legally the responsible for sanitation services and also outlines the obligations of the involved parties, presenting a systematic approach to management, focusing on planning, regulation, supervision, and service provision. It allows for various arrangements to fulfillment these activities. Through the instruments provided in this law (National Plan of Basic Sanitation – Plansab) it was possible to highlight the deficit related to basic sanitation services throughout the country, especially in rural areas (Brazil, 2013, Brazil, 2019).

Plansab played a crucial role in bringing rural sanitation to the forefront by recommending the creation of a National Rural Sanitation Plan (PNSR) for Brazil. PNSR emphasizes the importance of considering the specificities of different rural territories and their populations (Funasa, 2019). It was elaborated with the purpose of universalizing access to basic sanitation in rural areas through the promotion and implementation of actions that ensure equity, comprehensiveness, intersectoral, coordination, service sustainability, participation, and social control. This plan should address not only rural populations but also those living in traditional communities, such as farmers, residents of quilombos, indigenous peoples, riverside communities and population inside conservation units.

The PNSR envisions that the specific ethnic-cultural, social, economic, and territorial characteristics and singularities of these distinct population segments should underpin the choice of basic sanitation solutions to be adopted, both regarding the technology and the management model of the solutions (Funasa, 2019).

Investments in sanitation infrastructure up to the year 2038 is expected to reach approximately 80.19 billion reais (about 17 billion dollars). However, despite the detailed, modern, and creative nature of Plansab, the Brazilian government still lacks commitment to assume such goals and targets to implement the envisaged actions. Consequently, the absence of sanitation in rural areas persists, with a scarcity of solutions or even the absence of service provision (Roland et al., 2019).

Sewage treatment technologies applied in rural households

Porto et al. (2019) highlighted the inequalities that underlie rural sanitation in Brazil. Generally, households with better financial conditions were found to have better-equipped solutions, as they were able to afford the acquisition and maintenance of infrastructure. This situation also occurred when families received government program benefits. Thus, family income was a determining factor for access to sanitation services, with higher income associated with a greater probability of rural households having solutions considered more adequate (Porto et al., 2019).

It was also found that in areas with lower population density, where households are dispersed, the adoption of single-family solutions is common. Multiple-family systems were implemented in areas with higher concentrations of residences and were generally observed in peri-urban areas (Funasa, 2019).

The most used individual solution for sewage treatment in all Brazilian regions is the cesspit (Figure 1), a simple and cost-effective alternative that is part of the popular knowledge of rural communities throughout the country (Figueiredo et al., 2019a; Porto et al., 2019). It is usually constructed as an unlined hole dug near the bathroom, effectively functioning as both a septic tank and a soakaway pit (Funasa, 2015). Figueiredo et al. (2019a) identified that the average diameter and depth of cesspits are 1.3 m and 4.6 m, respectively.

Its use is quite prevalent in Brazil, with this type of disposal being adopted in 53% of households (Landau & Moura, 2016). In rural areas, the scenario is not much different from the national average: out of all residences served by sewage systems, approximately 48.6% dispose of sewage in cesspits (Brazil, 2019). When comparing these data with studies conducted in two municipalities in the state of São Paulo, even higher rates were observed, ranging between 60% and 81%, with the highest being in the rural area of Campinas, one of the wealthiest cities in this state and in the country (Figueiredo, 2019; Suprema, 2013).

However, despite the popularity and good acceptance by users of this type of sewage disposal, it is important to highlight that cesspits are generally built without any type of project or technical support, relying solely on the traditional knowledge of families (Alves Filho & Ribeiro, 2014; Figueiredo et al., 2019a; Larsen, 2010; Porto, 2016). In many communities, there are so-called 'cesspit builders' (fosseiros) who possess this traditional knowledge and experience for cleaning and constructing the pits.

Also, because of this and the heterogeneity of the terrain in the country, this technology presents variable characteristics in each region of the national territory, such as: the pi lining, the type of lid, pit dimensions, distance from the residence and water collection points, and the types of sewage disposed inside (Figueiredo et al., 2019a).

Despite that, Tonetti et al. (2018) assert, in agreement with WHO/UNICEF (2017) and Funasa (2015), that the cesspit is a technology capable of providing environmental safety and public health, as it prevents direct contact of people with sewage. However, it is important to conduct research to establish criteria for its sizing, construction, and operation, considering aspects such as appropriate distances from the water table and other pits, wells, or river sources, as well as defining the number of pits implemented per area, soil characteristics, sludge management methods, and criteria for alternating or restoring clogged pits (Figueiredo et al., 2019a). These authors suggest that if the cesspit poses no risk to public health and the environment by being properly sealed; maintaining a distance from other pits and water collection wells, having a distance from its bottom to the water table that does not harm the groundwater aquifer, it could be called as “absorbent pit”.

Many authors have found that to extend the lifecycle of cesspits most rural residents direct only toilet water (also known as black water) to this system (Figueiredo et al., 2019a; Roland et al., 2019). This creates conditions for another characteristic aspect of rural communities in Brazil: the separation of greywater from showers, bathroom sinks, kitchen sinks, laundry, and household cleaning from the water generated in the toilet.

Evapotranspiration tank

An alternative technology to cesspits for treating sewage from toilets, widely disseminated in Brazil and developing countries, is the Evapotranspiration Tank (TEvap) (Figure 2). The design of the TEvap was initially developed by John Watson (Vieira, 2010), who proposed an evapotranspiration system for toilet and/or greywater that eliminated the need for a septic tank and infiltration trench. This system became internationally known by Watson-Wick and was introduced in Brazil in 2000 by Scott Pitman (Pamplona and Venturi, 2004), and a few years later it was modified by Jorge Timmerman (Galbiati, 2009). However, it was the journal article by Pamplona and Venturi (2004) that was responsible for first disseminating the technology in the field of permaculture (Campos, 2018).

The TEvap consists of a waterproofed tank filled with different filtering materials arranged in layers. On its surface, species of plants with high evapotranspiration capacity are planted. Banana trees and taioba (Xanthosoma sagittifolium) are usually the plants used, but papaya (Carica papaya) and yam (Dioscorea spp) are also observed. In addition to these, there are ornamental plants such as calla lily (Zantedeschia aethiopica), busy lizzie (Impatiens walleriana), white ginger lily (Hedychium coronarium), heliconia (Heliconia farinosa), pampas grass (Zizanopsis bonariensis), and canna lily (Canna sp).

The advantage of this technique is the low production of sludge and the absence of final effluent. This makes the system safer, as there is no possibility of direct contact between the residual water and users. Additionally, since the system is built within a waterproofed box, there is no possibility of effluent infiltration and subsequent contamination of the soil or aquifer by pathogens and nutrients.

Despite being a technique known for over 20 years in Brazil, scientific data published in the literature are still scarce (Figueiredo, 2019; Paulo, 2019). In one of the few studies conducted over a significant period, social and efficiency aspects of applying this technology in a rural community located in the municipality of Campinas (São Paulo, Brazil) were addressed (Figueiredo et al., 2019b). The TEvap registered a removal efficiency above 90% for organic matter in terms of chemical oxygen demand (COD) and biochemical oxygen demand (BOD), as well as for total suspended solids. These results were quite similar to those found by Paulo (2013), who monitored a system built in another rural area near the municipality of Campo Grande (Mato Grosso do Sul, Brazil).

The system in Campinas (Figueiredo, 2019) was installed in a residence where the cesspit had problems with collapsing and rapid filling due to the shallow depth of the water table.

This technological alternative was very well-received by the residents and ended up being disseminated throughout the community. Its positive aspects were emphasized, with the main ones being ease of construction, shallow depth of the trench, and the possibility of food production (bananas and other fruits).

Biodigester septic tank

Another technology that has gained traction in Brazil and Latin America is the so-called biodigester septic tank (BST) (Figure 3). Over 11,000 units have been installed throughout Brazil, catering to approximately 57,000 people across different regions (Silva et al., 2017; Silva, 2018). In 2017, this technology was incorporated into the Brazilian National Rural Housing Program with the aim of serving around 35,000 households.

This system is utilized in households with up to five residents (Novaes et al., 2002; Galindo et al., 2010) and consists of three tanks with a capacity of 1,000 L each (Figure 3) connected in series. In the first two tanks, anaerobic digestion of sewage from the toilet occurs, while the last tank is responsible for storing the final effluent, which is called biofertilizer (Novaes et al., 2002; Galindo et al., 2010). The simplicity of installation, operation, and the generation of biofertilizer are the main attractions generally attributed to BST, which strongly contributes to the dissemination of the technology. The required maintenance consists solely of monthly addition of fresh cow manure mixed with water in a 1:1 ratio to enhance microbial activity and process efficiency, as well as to prevent the emission of bad odors (Novaes et al., 2002; Galindo et al., 2010).

However, some authors such as Barboni and Rochetto (2014), Oliveira (2018), and Figueiredo et al. (2019c) have questioned the necessity and role of cow manure in the treatment efficiency. Figueiredo et al. (2019c) found that in a set of physical and chemical parameters (BOD, COD, P, TSS, turbidity, and pH) monitored in the BST during a period of 8 months, no significant interference of the addition of cow manure was observed on the quality of the final effluent. According to the authors, this demonstrates that the use of this resource is unnecessary.

Furthermore, it is crucial to emphasize that the practice of irrigation with treated effluent raises significant concerns from both sanitary and environmental perspectives. As noted by Figueiredo et al. (2019c), the concentration of E. coli in the final effluent remains alarmingly high, ranging between $8.9x10^3$ and 3.1x104 MPN 100mL-1, thereby posing a potential risk for the spread of waterborne diseases. Therefore, exercising caution in its application as a biofertilizer is imperative.

During the management and application of biofertilizer, it is essential to use personal protective equipment such as gloves and closed-toe shoes. Additionally, it is crucial to ensure that areas where the effluent is superficially applied are inaccessible to domestic animals, thus minimizing contamination risks. However, in practice, these recommendations are often not followed by residents, making it more difficult to ensure health security (Figueiredo et al., 2019c).

Another concerning aspect is the frequent replacement of properly functioning absorbent pits with biodigester septic tanks (BST). In essence, a properly sealed absorbent pit that presents no threat to public health or the environment due to its adherence to safety measures such as maintaining distance from other pits and water wells, as well as maintaining a safe distance between its bottom and the water table, is decommissioned. Instead, a biodigester septic tank is installed, which brings wastewater to the surface along with all the associated risks of using effluent for irrigation near residential areas.

A study conducted by Miyazaki et al. (2024) concluded that the use of this system poses risks to human health. It was determined that the recycling of effluent from BSTs in agriculture could entail significant and unacceptable hazards. According to the authors, given the widespread adoption of this system across Brazil and other parts of Latin America due to its straightforward construction, its usage should only be allowed if additional control measures and treatment barriers are implemented. These may include refraining from adding fresh cattle feces and restricting the use of effluent for agricultural purposes solely to subsurface irrigation (Figure 3). Hence, there is a pressing need to pursue modifications in its design and construction. One potential solution could involve disposing of the effluent in infiltration trenches surrounded by fruit trees. These trees would absorb the infiltrated effluent, thus preventing animals from coming into contact with the moist soil and residents from exposure to wastewater.

Grey water generation and disposal

Greywater refers to all sewage generated in a residence, excluding that from toilets. This typically includes water used in kitchen and bathroom sinks, dishwashers, showers, and laundry machines (Li et al., 2009). It is estimated that in developing countries, the generation of gray water accounts for 50% to 80% of water consumption (Al-Gheethi et al., 2019). As commonly practiced, especially in rural areas of Brazil, toilet water is directed to a cesspit, while greywater is disposed onto the ground surface, where it flows until it either infiltrates the soil or reaches a water body.

Figueiredo et al. (2019d) observed that in addition to being separated, greywater underwent different treatment compared to the rest of the domestic wastewater. It was often subjected to what could be termed as 'intuitive' treatment, being applied directly to the soil (45%), or in proximity to plants such as taioba and fruit trees (32%), especially banana trees. These findings are aligned with those reported in PNSR (Brasil, 2019), which found that in only 12% of cases, greywater was directed to absorptive pits or septic tanks, and in 11% of the evaluated situations, it was disposed of directly into water bodies.

Porto (2016) observed that communities in the Brazilian states of Santa Catarina, Paraná, and Minas Gerais, there is a prevalent practice of directly disposing of greywater from the kitchens and laundry onto the ground. A study conducted in 171 rural households in Quixadá (Ceará, Brazil) indicated that in at least 96.5% of the homes, greywater was disposed of in areas near to the residences (Mello et al., 1998). Another investigation carried out in rural settlements in the state of Ceará showed that 98% of the water generated in the kitchen and shower was disposed of on the ground, as along with 99% of that from the sink or washing machine (Pinheiro, 2011). In Itaiçaba (Ceará, Brazil), 15 out of 16 evaluated households discharged greywater onto the ground without plant reuse. Meanwhile, in Prainha do Canto Verde (Ceará, Brazil), nearly 60% of the assessed households discharged gray water onto the ground without plant reuse, while 30% irrigated crops with gray water (Botto et al., 2005).

Greywater separation is considered a crucial step towards ecological effluent treatment as it allows for greater simplification and a more sustainable approach (Funasa, 2015). Therefore, the National Program for Rural Sanitation (PNSR) encourages this practice as a strategic guideline for the development of sanitation in rural areas of Brazil (Brazil, 2019). However, despite these efforts, Brazil still faces significant challenges in ensuring proper management and disposal of this resource. Nevertheless, the safe use of greywater for crop irrigation holds substantial environmental sustainability benefits, as it provides a new purpose to both water and nutrients.

Despite greywater having a lower potential for pathogen contamination compared to water from toilets, there is still a risk of waterborne diseases transmission. Figueiredo et al. (2019d) found high concentrations of total coliforms and Escherichia coli (greater than 105 NMP100mL-1) in water samples from showers and kitchen sinks in households located in a rural area of Brazil. High levels of Escherichia coli were also reported by Friedler (2004), particularly in shower water.

The microbial population in this type of effluent includes bacteria from the nose, the anus, and the mouth, as well as those from washing vegetables and raw meats, and from the hand hygiene after using the bathroom. The habit of urinating in the shower might also contribute to the presence of some types of bacteria. Washing diapers and underwear can also be a source of microbial generation (Morel & Diener, 2006). However, lower concentrations were observed in water samples from laundry washing. One explanation for this behavior could be the greater dilution and use of cleaning products (disinfectants, bleach, and soaps), which would contribute to reducing or eliminating the presence of microorganisms (Morel and Diener, 2006). The study by Newcomer et al. (2017) conducted in rural households in Malawi also observed lower concentrations of bacteria in samples from laundry and handwashing water.

Nevertheless, it is important to emphasize that Figueiredo et al. (2019d) found that all evaluated samples reached Escherichia coli values only slightly lower than those typically found in raw sewage or in rivers with a high degree of contamination. WHO (2016) recommends that the maximum number of Escherichia coli in water used for crop irrigation where the farmer has significant contact with the irrigated soil is 1.0x104 MPN 100 mL-1. Thus, regardless of the origin of greywater, this threshold value would still be exceeded for all the samples in Figueiredo et al. (2019d).

Hence, caution is necessary regarding its direct use in any agricultural activity, especially when considering that the application would occur in the surrounding area of the residence. This characteristic would facilitate the contact of children and animals with greywater, increasing the risk of pathogen contamination if the application is superficial.

Furthermore, Hardie et al. (2021) demonstrated that liquid and powder detergents can lead to the loss of humus and reduction in soil hydraulic conductivity. The authors state that powder detergents are more aggressive to the soil than liquid ones, not recommending the direct application of gray water from laundry if the washing cycle has been conducted using this type of detergent, even if at the proportions recommended on the product packaging.

However, in Brazil, this finding should be further evaluated, as the country experiences very intense rainy seasons. Thus, during the rainy period, does the intense influx of water into the soil end up diluting and leaching these compounds present in detergents and powder soaps? There is also the fact that in Brazilian rural communities, there is still more common the use of bar soaps for laundry washing, which are less environmentally harmful.

Another point to consider is that rural landowners would not use complex systems to pump gray water to distant locations from the residence, only to then carry out superficial application on the soil. The adopted practices would be the simplest and most economical possible, requiring minimal maintenance.

Thus, it is evident that the separation of greywater is a common practice in Brazilian rural communities, however treatment and reuse still pose a challenge as they are often carried out in an unplanned manner by residents themselves. Therefore, what would be the best disposal method for this segregated wastewater? One that allows for the use of water and nutrients while ensuring safety for public health and the environment?

Technologies for greywater treatment

Studies concerning the treatment and disposal of gray water, as found in the scientific literature, typically focus on reuse in urban areas. Many of these publications are based on studies conducted in developed countries in North America and Europe (Al-Gheethi et al., 2019; Morel and Diener, 2006). In such contexts, greywater undergoes some form of treatment and is repurposed for activities like flushing toilets, vehicle washing, or floor cleaning. These practices require costly treatment, disinfection, storage, and pumping of the liquid to facilitate the use of the treated effluent. Notably, there is a dearth of studies evaluating and addressing solutions suitable for the reality of rural households in developing countries.

In these cases, a fundamental aspect of managing greywater would be to prevent its flow over the bare soil surface. This would avoid contact with people, animals, and vectors, mitigating disease transmission by creating physical barriers between users and the effluent. Such action would also prevent the pooling of greywater and the consequent generation of unpleasant odors, as well as hinder the procreation of larvae (Figueiredo et al., 2018). This sanitary barrier would bring immediate benefits to public health, especially considering the spread of dengue (a disease transmitted by mosquitoes that depend on stagnant water for their life cycle) in Brazil and other tropical countries.

Common practices within communities (Tonetti et al., 2018) proffer several recommendations for treating greywater. However, it is important to propose technologies aiming to avoid the most common solution in rural areas: the unplanned deposition in the soil. Regardless of the chosen technology, it is crucial that greywater from kitchen sinks should pass through a grease trap. This pre-treatment step aims to retain fats, oils, and greases, thus preventing rapid clogging and soil blockage (Figueiredo et al., 2018).

A pathway towards sustainable greywater treatment entails adopting technologies that facilitate its subsurface infiltration near the residence. However, how can we make this beneficial practice more appealing to rural residents? One approach could involve permitting certain fruit-bearing plants access to the raw greywater. The daily availability of water and nutrients would bolster the growth of these plants, potentially leading to increased fruit yield (Marinho et al., 2013; Marinho et al., 2014; Gabrielli et al., 2015). This would engender satisfaction among users of the technology, who could feel more actively engaged with the treatment system.

Consequently, water and nutrients would be utilized by the plants, while the soil and roots would function as a sanitary barrier, preventing pathogens from reaching the edible parts (Leonel et al., 2016; Leonel et al., 2021; Leonel et al., 2022). Additionally, the soil would also facilitate the degradation of these pathogens through physical, chemical, and biological processes, the latter driven by natural predators. Thus, effective defense barriers between humans and pathogens, which would be the plants and the soil. Below are some suggested technologies that could align with these expectations.

Infiltration trench

The infiltration trench is widely used in the USA and Europe but remains less prevalent in Brazil, Latin America, and other developing countries. This technology involves the infiltration of wastewater into the soil, for treatment and final disposal (Figure 4).

The Brazilian standard NBR 13969 (ABNT, 1997) recommends its construction exclusively for the post-treatment of effluent from septic tanks. However, this standard is considerably outdated and disconnected from the reality of rural territories, as it does not account for the separation of wastewater generated in a residence, only providing design criteria for situations in which all sewage flows are combined.

However, the implementation of the infiltration trench for the treatment and final disposal of raw greywater would be highly beneficial and feasible for rural areas in Brazil. Since the system facilitates the final disposal of wastewater through its infiltration into the soil, there is no generation of effluent or its exposure in the surface, minimizing human contact and transmission of waterborne diseases.

It is essential to ensure that the infiltration trench is not located in saturated soils with a shallow water table, to prevent or hinder the contamination of the groundwater. On this matter, the standard NBR 13969 (ABNT, 1997) stipulates that the bottom of the trench should maintain distance from the water table of at least 1.5 meters as a precaution against groundwater contamination. However, it does not cite any literature source to support the adoption of this minimum value.

One positive aspect of the infiltration trench is its straightforward construction, as it does not require deep excavation. However, its main objective is still the final disposal of the effluent, without provision for wastewater reuse, even via plant roots. The Brazilian standard (ABNT,

1997) allows the cultivation of grass above the system, but there is no mention of planting edible crops.

The utilization of water and nutrients present in greywater could serve as a significant incentive for the installation this treatment system in rural areas of Brazil, given the country's experiences with climate change induced by global warming. Not only the semi-arid regions of the Northeast have been experiencing the traditional long periods of drought, but also the southeastern and southern areas have been affected by drier climates. Consequently, many locations have witnessed water well depletion and a deepening of the water table.

The use of greywater through infiltration trenches could be an important alternative to supplying water for edible crops planted near rural residences. However, how could we propose changes in its construction design to facilitate plant access to water and nutrients while maintaining a system that does not pose risks to public health or the environment?

An alternative infiltration trench should permit the use of greywater near the residence while ensuring sanitary conditions and minimizing environmental impacts. Adhering to this principle, certain fruit-bearing plants such as banana trees and papaya trees could be planted near the infiltration trench but maintaining a minimum distance of 3.0 meters. However, it is advisable to avoid planting species with aggressive root growth that could compromise the piping of the greywater distribution system. It is imperative to note that agricultural crops whose produce directly contacts the effluent, such as potatoes, carrots, cassava, beets, onions, garlic, etc. are not recommended.

Banana tree circle

Another system for treating greywater that has gained popularity in Brazil is the use of the banana tree circle. This technology entails excavating the soil in a bowl-shaped configuration, measuring approximately 2.0 meters in diameter and 0.80 meters in depth (Figure 5). Subsequently, this depression is filled with organic matter that decomposes slowly. Next, this hole is filled with organic matter such as small branches and then straw on the top or mulch. The straw comprises dry grass, banana leaves, and tree pruning, with the aim of establishing a well-aerated and expansive environment to accommodate greywater (Figueiredo et al., 2018). Vieira (2006) contends that a volume of 1 m3 is sufficient for treating greywater produced by a family of three to five people and Mudadu et al (2024) propose sizing the banana tree circle based on hydraulic load, soil percolation and evapotranspiration rate.

All the excavated soil from the depression is piled around its perimeter, where plants with high water demand, organic matter, and nutrient requirements, such as banana trees, are planted (Funasa, 2018). Alongside banana trees, lilies, papaya trees, and taioba plants can be cultivated, enhancing evapotranspiration and nutrient absorption (Funasa, 2015; Martinetti, 2015). Sewage must be conveyed through a pipeline that should reach into the straw, ensuring that the greywater remains submerged and shielded.

One of the main advantages of the banana tree circle is its affordability and straightforward construction, with maintenance primarily involving the replacement of branches and grass clipping/straw, along with fruit harvesting and managing surrounding vegetation growth. Therefore, it has great potential to be adopted by rural residents in Brazil, providing an alternative to the conventional unregulated disposal of greywater on the soil surface. Another important aspect is that this system enables plants to utilize water and nutrients, with any surplus being infiltrated into the soil. Moreover, the banana tree circle prevents greywater from being exposed on the soil, thereby reducing the risk of waterborne disease transmission. It is important to note that traditional knowledge about locating banana trees and other water-loving plants near greywater outlets is widely spread among Brazilian farmers (Figueiredo et. al., 2019 d), which makes the technology even more suitable for local conditions.

Technologies treating sewage without source separation

The NBR 7229 (ABNT, 1993) and NBR 13969 (ABNT, 1997) standards outline appropriate technologies for decentralized sanitation. However, these standards do not provide water source-separation, rather, they endorse the consolidation of all sewage from a residence into a single flow, which then must be directed to a conventional septic tank followed by post-treatment.

The post-treatment of the septic tank effluent can be accomplished through various methods, including anaerobic filters, aerobic filters, filtration trenches, sand filters, soakways, among others (De Oliveira Cruz et al., 2013; De Oliveira Cruz et al., 2018). The most prevalent design combines the septic tank with the anaerobic filter, which has received attention from numerous Brazilian universities. Several studies propose simplifications of septic tanks, aiming to streamline their construction (Tonetti et al., 2021; De Oliveira Cruz et al., 2019; Silva et al., 2015; Tonon et al., 2015; De Oliveira Cruz et al., 2013; Tonetti et al., 2012). Additionally, there is a proposal for utilizing prefabricated polyethylene water tanks, readily available in all construction material stores nationwide (Almeida et al., 2021). The adoption of such products holds the potential to reduce construction time and costs, facilitating their use in remote regions such as oceanic islands and riverside communities in the Amazon. Similarly, alternative construction methods for anaerobic filters have been explored, focusing on replacing traditional filling materials (stones and plastic) with more accessible alternatives like bamboo and green coconut husks (De Oliveira Cruz et al., 2019; De Oliveira Cruz et al., 2013). In Brazil, green coconut husks have become a problem because after the water is consumed, the husk becomes a waste, which is disposed of in landfills or thrown into the sea. Thus, using this material as filling for anaerobic filters would serve the purpose of waste disposal while reducing the system's construction cost.

Despite that, the popularization of septic tanks and anaerobic filters in rural areas would require the management of sludge produced in both reactors. If the system is installed near urban centers, its removal, transportation, and treatment could be considered by sanitation companies operating large sewage treatment plants. On the other hand, there is still a significant gap regarding the management of sludge generated in isolated locations and small districts. In such cases, on-site management may lead to improper removal of residue from inside the reactors, resulting in malfunction. Therefore, it is imperative for government agencies and universities to expand studies on this topic, seeking viable alternatives to address the issue of sludge management in Brazilian rural communities.

Moreover, it is essential to consider Brazilian environmental resolution Conama 498 (Conama, 2020), which prohibits the use of sludge from individual treatment systems, collected by vehicles, before its treatment by a sludge management unit licensed by the competent environmental agency in the soil. In other words, the sludge removed from a septic tank installed on a rural property cannot be managed by the homeowner.

While the combination of a septic tank with an anaerobic filter facilitates wastewater treatment, it generates an effluent that requires proper disposal. This can involve discharge into a water body or the soil. Direct discharging into a water body would require a sufficient flow rate to ensure adequate dilution and compliance with Brazilian regulation Conama 357 (Conama, 2005). However, rural residents often avoid constructing their homes near large water bodies due to flooding concerns, preferring to build near small streams, marshes, or springs, which complicates direct discharge of effluent. Alternatively, installing long pipelines to discharge points into rivers with higher flow rates would significantly increase project costs.

Other new technology

Vermifiltration emerges as another viable technology for treating greywater and combining all household wastewaters, presenting an attractive option for decentralized systems in rural areas due to its simplicity in operation and implementation (Tonetti et al., 2018).

Vermifilters, essentially aerobic biological filters, incorporate a layer of organic substrate with detritivorous earthworms, commonly used in vermicomposting processes (Figure 6). These earthworms facilitate natural aeration and granulation of clay particles, as well as breakdown of sediments and sand. Consequently, the specific surface area of the filtering medium increases, enhancing the capacity to retain both organic and inorganic compounds (Sinha et al., 2008).

The suspended solids present in the influent are captured at the vermifilter's surface, initially decomposed by the earthworms and subsequently processed by the microorganisms throughout the biofilter layers (Sinha et al. 2008). Natural aeration of the filtering medium minimizes the release of unpleasant odors. Furthermore, earthworms construct channels that enhances aeration and inhibits the microorganisms action (Sinha et al. 2008). Regarding performance, various studies have reported organic matter removal exceeding 90% in terms of BOD (Soto and Tohá, 1998; Taylor et al. 2003; Sinha et al. 2008; Li et al. 2009; Nie et al. 2014; Kumar et al. 2014; Arora et al. 2014; Lourenço and Nunes, 2017).

In studies focusing on rural communities sanitation conducted at a Brazilian university, vermifilters combined with septic tanks exhibited an overall organic matter removal of 81% in terms of COD and 86% in terms of BOD, demonstrating its feasibility (Madrid et al., 2019). This setup involved a substrate layer containing a mixture of dried brachiaria grass (a type of grass commonly known as Brachiaria) and soil, into which Eisenia andrei earthworms were introduced (Madrid et al., 2019). Brachiaria is a plant that has spread throughout Brazil, requiring frequent cutting and management of the generated residues. Therefore, its use in vermifilters would be of interest to rural area residents.

Comparatively, Nie et al. (2014) studied a full-scale vermifiltration system consisting of an anaerobic filter with gravel as support material followed by two vermifilters. The reactors were employed for the treatment of sanitary sewage from family residences in a rural village in the city of Yixing (Jiangsu/ China). The authors reported an overall removal of over 90% of organic matter in terms of COD throughout the entire analyzed period.

In seeking greater simplification of the system to enhance the feasibility of employing this technology in rural communities, Brazilian researchers examined a vermifilter configuration with a substrate layer composed of sawdust for the direct treatment of raw sanitary effluent (Madrid et al., 2019). In other words, they evaluated whether the removal of pre-treatment by a septic tank or anaerobic filter caused any issues for the vermifilters. The results obtained for the removal efficiency of organic matter in terms of BOD and COD remained similar to those achieved with the presence of pre-treatment and were consistent with those reported by other authors (Soto; Tohá, 1998; Xing et al., 2010; Liu et al., 2013; Nie et al., 2014).

Another important characteristic of the technology is the generation of vermicompost rich in nutrients on the surface of the reactor. However, there is still a need for further study regarding its potential use as a biofertilizer. It's worth noting that there is a significant presence of pathogens retained by the bed in this surface layer.

There is also the potential for effluent reuse for non-potable purposes, such as irrigation, floor washing, and toilet flushing (Xing et al. 2005; Sinha et al. 2008; Liu et al. 2009). However, this should be discouraged in rural communities or household units. The practice of reuse requires attention and constant supervision which is usually incompatible with the dispersion of residences in rural Brazilian areas. Therefore, we should aim for effluent infiltration through infiltration trenches or its use through alternative infiltration trenches, which were presented in this article.

It is worth noting that, concerning the various aspects that constitute a vermifilter, there are still no (Brazilian or international) standards for sizing or recommendations for materials that can be used in the filtering bed. In the scientific literature, various compositions have been studied, although there is still no consensual guideline. Therefore, the use of this technology should be carefully evaluated before seeking its dissemination for the treatment of wastewater generated in rural areas. Otherwise, this system may be poorly perceived by rural residents due to problems that could have been corrected through more attentive monitoring on a pilot scale.

II. CONCLUSION

The issue of sanitation in rural areas of Brazil and other Latin America countries continues to present a significant challenge. In Brazil, despite the presence of a modern and creative national rural sanitation plan (PNSR), the effective implementation of state – led initiatives to meet these commitments and goals remains in its infancy.

Most of the solutions implemented rely on the traditional knowledge of rural families, often lacking the support of formal projects, regulatory and technical frameworks, as well as financial incentives. For instance, the cesspool pit commonly adopted as the primary solution, while more recently biodigester septic tanks (BSTs) have gained popularity. However, concerns persist regarding the proper guidance for using BST effluent in agricultural irrigation.

In Brazil specifically, a practice observed in rural areas involves the separation of greywater from toilet waste. This distinction opens the door to new technologies, such as the evapotranspiration tank, which exclusively treats water originating from the toilet and does not allow effluent infiltration, thus preventing soil or aquifer contamination by pathogens and nutrients. Infiltration trenches are also promising and feasible options, but the establishment of standards mandating the separation of household wastewater is necessary for their correct dimensioning and widespread adoption. One potential solution for treating greywater is the implementation of banana tree circle, which facilitates plant utilization of water and nutrients by plants while the excess is infiltrated into the soil. The use of a septic tank followed by an anaerobic filter can also be considered in rural areas when all wastewater generated in a household is combined. However, a significant challenge in promoting their adoption lies in effectively managing the sludge produced by both reactors.

Therefore, while there are technologies available to address the deficit in wastewater treatment in rural areas, it is imperative to ensure their proper adoption among the population and to bolster state intervention in implementing national plans and revising standards and guidelines..

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