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IMPLEMENTATION OF DECENTRALIZED SANITATION SYSTEMS WITH NATURE-BASED TECHNOLOGIES: ADVANTAGES AND CHALLENGES IN RURAL AREAS, SLUMS AND URBAN COMMUNITIES

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Abstract: There is a growing gap in basic sanitation services in Brazil, highlighting the notable inequality in access to these services, especially in less favored territories. According to the 2022 Demographic Census, almost 50 million Brazilians live in households that use precarious sanitation resources. Nature-Based Solutions (NBS) are presented as a way to interfere in sanitation in rural areas, slums and urban communities, since they use natural processes to solve problems for which traditional solutions are unfeasible. This study aims to present 16 individual decentralized sewage systems as alternatives to contribute to solving the lack of basic sanitation and show the advantages of implementing these NBS for sanitation in rural areas, slums and urban communities. Such solutions can meet sanitation needs in a sustainable way, using natural processes and local technological resources, while respecting ecological cycles and promoting environmental, social and economic benefits. We adopted a Critical Analysis approach, based on a bibliographic review of works and research related to the field of study. Funasa (2015), Tonetti et al. (2018) and Vieira (2020) present NBS with individual and decentralized sewage solutions. This approach allows us to verify the patterns, benefits and limitations of these solutions. This work contributes to the understanding of the relevance of these alternatives in promoting health, mitigating social inequalities and providing sustainable sanitation.

Keywords: Nature-Based Solutions. Basic sanitation. Sewage service. Individual and decentralized sewage systems. Slums and urban communities.

INTRODUCTION

Brazilian homes, especially those located in rural areas, slums, and urban communities, often lack adequate sewage solutions. In cases where these solutions exist, they are improvised and precariously constructed. Among the alternatives found, rudimentary septic tanks (cesspits), open-air disposal, and direct disposal of waste into bodies of water, such as streams and mangroves, stand out (Instituto Trata Brasil, 2016). In these places, the incidence of waterborne diseases is evident, in addition to considerable environmental degradation. Additionally, there are a series of deficiencies that affect not only urban aspects, but also human and social dimensions, highlighting the depth of the challenges presented (Heller, 2022).

The Thematic Diagnosis of Sewage Services presented by the National Sanitation Information System (SNIS) reports that, in 2020, 55.8% of the country's population was served by sewage collection services. However, it is important to highlight that a significant portion of citizens remain without access to sewage systems through public collection networks, according to the Ministry of Regional Development (MDR, 2022).

Nature-Based Solutions (SBN)[1] are presented as a sustainable and economically viable form, characterized by interventions that use natural processes to solve environmental, social and economic challenges in rural and urban areas (Villanova, 2022). According to Fraga (2020), NBS benefit the environment, promote productive economic activities and improve the quality of life of communities. Recently, such resources have gained prominence in the field of urban and regional planning, being adopted as a response to the growing demand for sustainability and resilience. NBS address a wide range of territorial problems, from the restoration

1. In English: *Nature-Based Solutions (NBS).*

of ecosystems to protect regions against extreme climate events to the implementation of basic sanitation infrastructures (IUCN, 2016, 2020a, 2020b). This study aims to present 16 individual decentralized sewage systems as alternatives to help solve the lack of basic sanitation and show the advantages of implementing these NBS for sewage in rural areas, slums, and urban communities, based on Funasa (2015), Tonetti et al. (2018), and Vieira (2020). The systems chosen were those that can be applied to single-family homes. Some of these systems can also be adapted for use in multifamily homes, with the aim of preserving the environment, ensuring financial viability, promoting tangible progress in the quality of life and health of individuals, and protecting nature (Vieira, 2020).

Even with the advances achieved, there are still approximately 1.2 million people who face inhumane conditions, having to relieve themselves outdoors, living in homes without bathrooms, toilets, or holes for waste disposal (IBGE, 2024a). Therefore, it is necessary to carefully revisit future perspectives, quality of life, sustainability and ecology. This implies analyzing the human dimension of basic sanitation and other elements related to this knowledge that affect human life and its particularities, especially those linked to the working class, the most disadvantaged and peripheral populations. This is a significant legacy of science and its practices to reduce the great social inequality that exists in Brazil (Philippi Jr.; Malheiros, 2005).

This research seeks to answer the following question: *How can Nature-Based Solutions, through the implementation of individual decentralized sewage systems, meet sanitation needs in rural areas, slums and urban communities, presenting environmental, social and economic benefits?*

THEORETICAL FRAMEWORK

Nature-Based Solutions (NBS) were initially developed by the International Union for Conservation of Nature (IUCN), encompassing actions and technologies aimed at sustainably managing, protecting and restoring ecosystems degraded by human activities. NBS have the capacity to simultaneously benefit society and nature, and are a promising approach to address global challenges such as environmental degradation and the emission of Greenhouse Gases (GHGs) (IUCN, 2016, 2020a, 2020b). The application of these solutions in urban and rural environments brings advantages for both biodiversity and social, economic and productive sectors (Funasa, 2015; Tonetti et al., 2018; Vieira, 2020). These technologies have been increasingly adopted as a response to demands for sustainability, especially in solving urban, industrial and agricultural problems, such as water reuse in domestic and industrial contexts, conservation of green areas to increase the permeability of cities and prevent flooding, basic sanitation solutions and restoration of ecosystems to improve the urban microclimate. In addition, NBS are effective in conserving biodiversity, contributing to the reduction of contact between disease vectors and humans (Fraga, 2020).

In the problem of sewage in disadvantaged areas, there is no single solution that can be implemented in a standardized way. In each situation, an alternative can be adopted that must take into account local peculiarities, without losing sight of environmental, human, social and health aspects (Vieira; Valério Filho; Mendes, 2024).

Adequate sewage treatment is crucial to prevent or reduce negative impacts on health, the environment and the social and economic development of a region, since sewage is a potential source of pollution. For people's health and well-being, the correct final disposal of sewage plays a vital role (Nuvolari, 2021). Improper disposal of human waste is associated with a series of diseases, including hookworm, ascariasis, amoebiasis, cholera, infectious diarrhea, bacillary dysentery, schistosomiasis, strongyloidiasis, typhoid fever, paratyphoid fever, salmonellosis, taeniasis and cysticercosis, according to the Sanitation Manual of the National Health Foundation (Funasa, 2015).

Regarding the way in which diseases associated with improper sewage disposal are transmitted, the main route is direct contact with waste, especially considering that the predominant destination of untreated domestic sewage in slums and urban communities is open-air ditches or bodies of water. This contributes to the emergence of various diseases, either through ingestion or contact with the skin and mucous membranes. Furthermore, the dumping of sewage directly into the soil can be responsible for diseases acquired through contact of feet and hands with contaminated soil. In addition to these effects, the inadequate disposal of sewage into the soil can lead to water contamination (Funasa, 2015).

Brazil's exacerbated urban growth has led to a significant increase in the number of inhabitants living in precarious conditions in slums and urban communities, especially in the states of São Paulo and Rio de Janeiro, considering the population density. The lack of public policies and inclusive urban planning has led to a rapid expansion of these housing units, characterized by a lack of infrastructure and sanitation (Maricato, 2015). In this context, urbanization is closely linked to the dynamics of the real estate market, shaped by the logic of capitalist accumulation. This results in the significant expulsion of the less privileged classes to peripheral areas, hillsides and urban suburbs, generating an urban and housing crisis, evidenced by precarious housing and living conditions (Villaça, 2012).

The capitalist city excludes the poor, since private ownership of urban land requires an income that the economy does not guarantee to the majority of the population. Some of them end up living in places where private property rights do not apply, such as in areas of public property or on land left vacant due to speculation (Villaça, 2011). When private property rights are reinstated, residents are evicted, highlighting the contradiction between economic marginality and the capitalist organization of land. The exclusion of low-income individuals in the capitalist city, which is based on private ownership of urban land, requires an inaccessible income for many to occupy urban space. Furthermore, landowners play a crucial role in the production of this space, influencing its access and its unequal distribution (Singer, 1985).

Within the context of capitalist logic, the various forms of access to housing in cities are intrinsically linked to the spatial contradictions originated by the social relations of production. These contradictions manifest themselves through conflicts related to land use and access to urban infrastructure (Villaça, 2012). Data released by IBGE (2020) indicate a significant increase in slums and urban communities in the country, reaching 13,151, with 5,127,747 households. This scenario encourages reflection on the urbanization process driven by the capitalist mode of production and the resulting disparities in access to housing and social and economic infrastructure. Slums and urban communities emerge as a visible manifestation of socio-spatial inequalities (Harvey, 2005, 2014). In this sense, we highlight the need for sustainable solutions for sanitation in rural areas, slums, and urban communities. NBS offer a promising approach, integrating

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environmental conservation with the improvement of sanitation infrastructure (CGEE, 2020). By adopting decentralized individual systems, it is possible to meet the needs of these communities more effectively, respecting local particularities and promoting the active participation of residents. NBS not only help mitigate negative impacts on health and the environment, but also contribute to reducing social inequalities, offering a viable and sustainable path towards inclusive urban development and the preservation of natural resources (Fraga, 2020).

METHODOLOGY

We adopted a Critical Analysis approach (Estrela, 2018) with the aim of identifying patterns, benefits and limitations of NBS for sanitation. We seek to provide a consistent basis for discussions and conclusions that aim to mitigate inequalities in access to sanitation services in rural areas, slums and urban communities. To achieve this purpose, we used a methodology that includes the analysis of works, technical and scientific articles, as well as research reports (Marconi; Lakatos, 2021).

Funasa (2015), Tonetti et al. (2018) and Vieira (2020) present NBS as individual and decentralized sewage solutions. For this research, we will present 16 alternatives that we consider relevant and viable, listed by these publications, for sanitation problems.

The term "slums and urban communities" is adopted in this study based on the new definition of the Brazilian Institute of Geography and Statistics (IBGE, 2024b), which conceives them as residential areas that emerged from autonomous and collective efforts of the population. These areas develop in response to the scarcity of effective public policies and the lack of private investment in housing, reflecting the lack of commitment to meeting fundamental housing needs, in addition to the lack of provision of spaces for commerce, services, leisure and culture, with the aim of ensuring the right to the city (Vieira, 2023).

INDIVIDUAL AND DECENTRALIZED SEWAGE SOLUTIONS

Given the problem of sewage disposal in rural areas, slums and urban communities, this study seeks to present Nature-Based Solutions (NBS) that can be applied to different contexts, respecting the specificities of each location and promoting social inclusion and environmental conservation.

The comparative analysis of these alternatives takes into account aspects such as the type of household sewage system, the area required to serve a family of up to five people, the type of sewage treated and the need for sludge removal. Below, we present a brief description of each of the 16 alternative solutions to sewage disposal problems, evaluating their characteristics and implementation requirements. These alternatives are based on Funasa (2015), Tonetti et al. (2018) and Vieira (2020).

VERMIFILTER

The Vermifilter is a single-family or semi-collective sewage system used to treat domestic sewage, including toilet water, grey water or pre-treated sewage. The system is divided into two parts: the upper part, composed of wood sawdust, humus and earthworms; and the lower part, formed by filtering materials, such as small-grain stones organized in alternating layers. The earthworms, especially the Californian worms, are responsible for the initial degradation of the organic matter, and the microorganisms perform the more refined decomposition.

The main advantage of this system is the production of humus in the upper layer, which can be removed and used as fertilizer. The vermifilter is generally built with concrete pipes, bricks, plastic drums, water tanks or other materials that guarantee watertightness, with a depth of approximately 80 cm. The sewage is continuously discharged into the upper part, the liquid part of which flows through the layers of sawdust and worms, and then continues to be filtered by the materials in the lower part.

The treated sewage is collected by a pipe with small holes in the lower part, after passing through the sawdust and filter material. For a family of five people, an area of 2 m² to 4 m² is required. It is recommended to install a pre-treatment unit, such as a septic tank, before the vermifilter, to help with failures caused by temperature variations and residues of chemical products, such as detergents, which can harm the worms.

The vermifilter can be built for a daily sewage volume of between 400 and 1000 l/m², with a layer of sawdust/worms 40 cm deep. Every six months, it is recommended to remove excess humus and replenish the sawdust layer to its initial height. The removed humus must be dried in the sun and can be used as fertilizer, although it is not recommended for vegetable gardens.

BIO-DIGESTER SEPTIC TANK

The Biodigester Septic Tank is a single-family sewage system developed by the Brazilian Agricultural Research Corporation (Embrapa, 2001) to treat wastewater from toilets. The system consists of three interconnected water tanks where organic material is degraded and sewage is transformed into biofertilizer, which can be used in some crops. This system is intended only for treating sewage from toilet flushes and is not recommended for treating gray water. The system consists of three 1,000-liter water tanks each, connected by 100 mm sewage pipes with fittings and sealing materials. Sewage enters through the top of the first tank and continues to the 2nd and 3rd tanks through pipes that come out of the bottom of each one. The third box serves as a storage tank for biofertilizer, which can be applied to fruit trees, but not to vegetables, greens or fruits and vegetables that grow close to the ground.

The area required to implement this system for a family of five people varies from 10 m² to 12 m², without the need for pre-treatment of sewage. The box can be built with various materials, such as fiber cement, fiberglass and concrete rings. It is recommended to apply fresh cow manure mixed with water monthly to improve the formation of a community of microorganisms, making the decomposition process of organic matter more efficient, although some recent research questions this recommendation.

CIRCLE OF BANANA TREES

The Banana Circle is a single-family domestic sewage system used for the supplementary treatment of sewage or gray water. The effluent is directed to a circular ditch filled with branches, gravel or stones at the bottom. Banana, papaya, taro and other plants are planted around the ditch to help treat and reuse the effluent, since the water and nutrients are absorbed by the plants, and the organic remains are degraded by microorganisms present in the soil. This system is an effective alternative for the supplementary treatment of septic tank effluent and its final disposal, and its implementation must be avoided in places with sandy soil and near water tables and springs.

It is necessary to dig a dish-shaped hole, with a depth of between 0.5 m and 1 m, and a diameter of between 1.4 m and 2 m. The hole must be filled with branches, dry grass, twigs and vegetable remains, in order to ensure ventilation and sufficient space to receive the effluent to be treated. Banana trees must be planted around the hole, spaced 60 cm apart. Other smaller species such as lilies, taiobas and papaya trees can be included. If the volume of effluent produced exceeds the absorption capacity of the Banana Circle, another circle can be built and the flow divided between the two systems.

GREEN SEPTIC TANK

The Green Septic Tank (or Evapotranspiration Basin - BET) is a single-family sewage system used to treat wastewater from toilets. This system is made up of three parts: a central part for receiving and initially digesting the effluent, a filtering layer, and an area for planting banana trees, also known as an evapotranspiration tank, eco-septic tank, bioseptic tank, plant bioremediation, banana tree septic tank or bioseptic bed. A box-type reservoir is excavated, which is buried and waterproofed, and can be made of concrete, masonry or PVC sheets/tarps.

The sewage enters through a 100 mm pipe and is dumped into the central chamber at the bottom of the tank, where the solids settle and the sewage digestion begins. In the central chamber, the sewage passes through filtering layers, which are generally composed of rubble, gravel or sand, materials in which microorganisms develop that degrade the sewage anaerobically. Above the filtering layer, banana trees, taiobas and marsh lilies are planted, which use the nutrients present in the sewage. For inspection and removal of sludge, it is necessary to install 100 mm pipes to the central chamber, allowing maintenance by a septic tank cleaning truck, although this rarely occurs. The use of materials such as old tires and hollow bricks is also common in the construction of the filtering layer.

FILTRATION DITCH AND SAND FILTER

Filtration trenches and sand filters are technologies used in single-family or semi-collective domestic sewage systems, designed to treat pre-treated sewage, usually after passing through a septic tank. These trenches consist of an upper layer of sand, with layers of other filtering materials below that have larger particles (gravel and rolled pebbles). Sewage is treated by filtering the particles and degrading the organic material by microorganisms present in the sand and filtering materials. The depth of the trench varies between 1.20 m and 1.50 m, and the width at the bottom is 0.50 m, with a 100 mm pipe at the bottom of the trench.

The receiving pipe must be surrounded by a layer of gravel no. 1, with a thickness of no less than 0.50 m, and covered with coarse sand or similar material, forming the filter bed. A drainage pipe with a 100 mm tube must be laid on this layer of sand to distribute the effluent from the septic tank. The dimensions and construction details of this domestic sewage system are regulated by NBR 11799/90 and NBR 13969/97.

After appropriate treatment, the final disposal of the sewage must be carried out in accordance with local environmental characteristics and the quality of the treated sewage, in compliance with environmental legislation.

CONSTRUCTED FLOOD SYSTEMS

The Constructed Wetlands (SAC)[2], they are used to treat pre-treated sewage and gray water in single-family or semi-collective configurations. These systems consist of trenches with waterproofed walls and bottoms, allowing the flooding of wastewater, with a depth of less than 1 m. Aquatic plants or macrophytes act to remove pollutants and fix

2. They are also known as Root Zones or Wetlands.

microorganisms that degrade organic matter. The typical shape of the SAC is rectangular, dug into the ground, with waterproofed walls and bottoms (masonry or synthetic blankets).

The size of the SAC depends on the daily volume of sewage, estimated at 2 m^2 per inhabitant, with a depth of 0.60 m to 1 m. The plants that make up the system must be pruned periodically, at least every six months, to ensure the efficiency of the treatment. The final destination of the sewage must comply with the limits established by environmental legislation.

COMPACT UPFLOW ANAEROBIC REACTOR

The Upflow Anaerobic Reactor (RAFA)[3] Compact is a single-family or semi-collective sewage system designed to treat toilet water or domestic sewage. Wastewater enters through the bottom of the reactor, traveling through the unit until it reaches the outlet at the top. This upward flow keeps the reactor always full of sewage. Inside, a sludge is formed with microorganisms that decompose organic matter without the presence of oxygen (anaerobic degradation).

At the top of the reactor, plates separate the liquid from the solid materials and the naturally formed biogas.

The dimensions and construction process are standardized by NBR 12209/2011. The area required to implement this system for a family of five people varies from 1.5 to 4 m^2, and it can be built with plastic pipes, concrete rings, masonry or any other impermeable material. It is recommended that the reactor be cleaned internally annually and that a ventilation system be installed in the pipes.

BIODIGESTER

The Biodigester is a single-family or semi-collective sewage system designed to treat toilet water or domestic sewage. This system consists of a closed chamber where the anaerobic digestion of organic matter occurs and a gasometer that stores the biogas produced, which can be used as cooking gas. The "Chinese" model, which is built in brick masonry and has a dome-shaped gasometer, is widely used in Brazil.

The area required to install a biodigester for a family of five is approximately 5 m^2. Excess sludge from the biodigester must be removed every two to four years, through the compensation box or through the dome lid. This system efficiently treats domestic sewage and provides a sustainable source of energy in the form of biogas, contributing to reducing environmental impact and promoting sustainability.

COMPARTMENTED ANAEROBIC REACTOR

The Compartmentalized Anaerobic Reactor (RAC) is a single-family or semi-collective sewage system used to treat toilet water or domestic sewage. Similar to a septic tank, it has several chambers arranged in series, which improves treatment efficiency.

It can be built with various impermeable materials, such as concrete rings, masonry, plastic drums or water tanks. The sludge accumulated in the RAC must be removed at defined time intervals.

3. RAFA is also known by the acronym UASB (from the English: *Upflow Anaerobic Sludge Blanket*).

INFILTRATION DITCH

The Infiltration Trench is a form of single-family domestic sewage system used for the complementary treatment of sewage in soils with characteristics that allow the absorption of effluent from a septic tank. The percolation of the liquid in the soil facilitates the mineralization of the sewage, preventing it from becoming a source of contamination of groundwater and surface water.

The trenches are excavated in land with a depth of between 0.60 m and 1.00 m, and a minimum width of 0.50 m and a maximum of 1.00 m, and must be laid with drainage pipes with a diameter of 100 mm. To dispose of the effluent from a septic tank, it is recommended to use at least two infiltration trenches, with a maximum length of 30 m each. The effluent, after the removal of organic matter, can be disposed of in the environment or eventually reused safely.

INTEGRATED BIOSYSTEM

The Integrated Biosystem (BSI) is a single-family or semi-collective sewage system designed to treat toilet water or domestic sewage, based on the ecological principles of total use of sewage through a treatment cycle. The BSI begins with a biodigester that can receive all the sewage or just the toilet water, where the anaerobic digestion of the organic material occurs, and the biogas generated can be used as fuel.

The sludge accumulated in the biodigester and in the anaerobic filter must be removed periodically. This system promotes efficient treatment of domestic sewage, integrating the generation of biogas and sustainable waste management, in line with ecological principles.

DRY PITS OR PRIVATE PITS WITH DRY PITS

The Dry Pit is a human waste treatment unit that does not use water for flushing, and is designed to receive only excreta and toilet paper. It is an ideal alternative for places with water shortages or without a water supply service. It is a hole dug in the ground, over which a small house is built, and which may or may not be lined. It usually has a circular opening of 90 cm in diameter or a square opening with sides of 80 cm, with an average depth of 2.5 m.

It is recommended to install a ventilation pipe to prevent the accumulation of gases inside the pit. It must be built away from wells and springs, and in places that are not subject to flooding or downpours. If there is a bad smell, it is recommended to cover the waste with lime, soil or ash. It is important that there is no water inside the pit, and that the hole remains covered to prevent flies from entering.

FERMENTATION PIT

The Fermentation Pit is an alternative to single-family or semi-collective sewage treatment designed exclusively for the treatment of feces and urine. It consists of two contiguous and independent chambers that receive waste directly, without the need for flushing, and works in a similar way to a Dry Septic Tank. This pit can be installed in an external house, and the fermentation chambers can be built in masonry.

One of the chambers is used until its capacity is exhausted, when it is isolated to allow the mineralization of the material. During this mineralization period, the second chamber is used. After mineralization, the material can be removed and the chamber reused, ensuring a continuous cycle of use and treatment. This method is effective and sustainable, especially in areas with water shortages or without access to conventional sewage systems.

SEPTIC TANK

The Septic Tank is a horizontal and continuous sewage system, designed for the local treatment of toilet water or domestic sewage in homes, small factories and buildings in rural areas. It works by separating light and heavy solids, decomposing them in an anaerobic environment. This simple, non-mechanized unit is easy to operate and low cost, consisting of a chamber that stores sewage for a certain period, allowing the sedimentation of solid materials and the floating of oils and fats. The solids deposited at the bottom form a sludge that houses microorganisms responsible for the degradation of organic matter. Its construction can use concrete rings, bricks or any material that guarantees waterproofing of the walls and bottom, with a minimum depth of 1.50 m. The sewage enters through the top and is retained for 12 to 24 hours, depending on the characteristics and daily volume. During this period, up to 70% of the suspended particles sediment, forming sludge. Non-sedimentable solids, such as oils and fats, are retained on the surface of the liquid, forming a layer of scum. Both accumulated sludge and scum must be removed and disposed of properly.

COMPOSTABLE DRY TOILET

The Composting Dry Toilet is a popular strategy for single-family or semi-collective sewage disposal, designed to treat only feces and, in some cases, urine, without using water for flushing. The waste is confined to a waterproof chamber located below the evacuation seat.

In addition to feces, sawdust is added with each use, providing ideal conditions for composting. This system can be installed in an external house or inside the residence, with the chamber built in masonry or with plastic containers.

When the chamber is almost full, it must be switched to another seat or, in the case of using drums or buckets, replaced with an empty container. This method facilitates the safe treatment of human waste and contributes to the production of organic compost.

ANAEROBIC FILTER

The Anaerobic Filter is a single-family or semi-collective sewage system designed to treat pre-treated domestic sewage, consisting of a chamber filled with filtering material that promotes the fixation of microorganisms responsible for the degradation of dissolved organic matter. It is recommended that this filter be preceded by a septic tank, biodigester or anaerobic reactor to optimize the process. It can be built with concrete rings (zimbras), masonry or any waterproof material that ensures the watertightness of the walls and bottom. There are also prefabricated models available on the market.

The maintenance of the anaerobic filter does not have a set frequency, but excess accumulated sludge must be removed periodically through the cleaning pipe. This system is efficient for reducing the organic load of the sewage, contributing to improving the quality of the final effluent.

RESULTS AND DISCUSSIONS

We understand that NBSs with technologies for individual and decentralized sewage treatment in rural areas, slums and urban communities meet sanitation needs in a sustainable manner and promote environmental, social and economic benefits.

The implementation of these solutions contributes to environmental conservation by minimizing soil and water pollution, in addition to improving the quality of life of communities through the creation of local jobs, promotion of public health and social inclusion. Therefore, NBSs stand out as a viable and sustainable alternative to address sanitation challenges in vulnerable contexts, aligning with sustainable development goals and the urgent need to reduce inequalities in access to basic sanitation services. Individual and decentralized sewage treatment solutions are increasingly gaining prominence as viable responses to overcome the deficiency in the adequate provision of sewage services in rural areas, slums and urban communities. These solutions are essential in view of the emerging challenges and approaches in the Brazilian reality, marked by the precariousness of these services and uncertain future prospects. Integrating the concept of Nature-Based Solutions (NBS), these technologies use natural processes to provide sustainable and effective sewage management, promoting environmental conservation and improving sanitation infrastructure (Funasa, 2015; Tonetti et al., 2018; Vieira, 2020).

Regarding financial and technical advantages, it is important to consider responsibilities, functionalities and technical guarantees. Therefore, here are some advantages for implementing these solutions for individual and decentralized domestic sewage treatment systems, according to Funasa, 2015; Tonetti et al., 2018; Vieira, 2020:

1) reduced cost, due to simple operation and compliance with current market standards;

2) offering of products, tools and materials, with several alternatives, which reduces expenses related to resources and labor;

3) reduced energy consumption, accompanied by low maintenance costs, with no charges for treatment and other procedures;

4) certain systems generate by-products that have the potential for reuse, such as fertilizers and useful items in different contexts, which can be used in engineering projects;

5) it avoids the need to build a conventional sewage system, which is often unfeasible due to the requirement of substantial investments and the use of costly techniques; 6) it does not require the hiring of highly specialized workers. The human, social and environmental advantages of individual and decentralized sewage treatment solutions represent an important qualitative difference and play an extremely vital role. This is true even when compared with the technical and economic aspects, which have traditionally received greater emphasis. Funasa (2015), Tonetti et al. (2018) and Vieira (2020) present the following advantages and respective processes, which can be identified as the most significant: 1) creation of jobs and income opportunities by recruiting local workers, which generates an impact on the economy and the social fabric, providing direct and indirect, short- and long-term jobs; 2) organic emergence of needs, jobs and occupations, which result from the expansion of the project and the creativity and actions of the people directly or indirectly involved. This includes everything from the intellectual processes of planning, implementation, operation and maintenance, to the identification and meeting of new requirements that may arise; 3) contribution to the substantial improvement of health and quality of life, which triggers positive impacts on environmental conservation and emphasis on valuing life and collective well-being; 4) these individual domestic sewage systems are well received in communities due to their conformity with local habits and culture, as they take into account cultural and ecological elements; 5) low energy consumption,

since softer and renewable technologies cause less impact on the ecosystem and have the capacity to be sustainable for a longer period; 6) significant reduction in soil and water pollution, which impacts the health, well-being and quality of life of communities.

CONCLUSION

We could conclude that Nature-Based Solutions (NBS) alternatives for sanitation, focusing on individual decentralized systems, meet sanitation needs in a sustainable manner, promoting environmental, social and economic benefits in rural areas, slums and urban communities. These individual and decentralized solutions emerge as a viable response to address gaps in sanitation services in disadvantaged communities. However, it is important to emphasize the importance of public policy support for the effective implementation of these solutions.

In financial and technical terms, NBS offer several significant advantages, including low implementation costs, energy efficiency and the possibility of producing reusable by-products. In some cases, these solutions eliminate the need to build conventional sewage systems, promoting the creation of local jobs and contributing to improving the health and quality of life of communities. Socially and environmentally, NBSs stand out for creating jobs, improving public health, reducing pollution, and promoting social inclusion, which contributes to environmental conservation by minimizing soil and water pollution. Obtaining accurate and up-to-date data on the implementation and effectiveness of NBSs in basic sanitation was the greatest challenge for this research, due to the scarcity of specific empirical studies. These difficulties highlight the need for a continuous and collaborative effort between researchers, public authorities, and local communities to overcome the challenges and promote the adoption of sustainable sanitation solutions. Given the above, this work contributes to the understanding of the relevance of these alternatives in promoting health, mitigating social inequalities, and providing sustainable sanitation. We suggest that future studies explore the effectiveness of different types of NBSs in different climate regions, assess the impact of these solutions on public health, and investigate financing models and public policies that encourage the adoption of these practices.

This study also highlights the importance of prioritizing adequate sewage treatment as an efficient sanitation measure and as a strategy to address social and environmental inequalities. The implementation of individual and decentralized sewage treatment solutions therefore emerges as a relevant approach to address this complex issue, promoting tangible benefits for individuals and the environment.

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