WHAT A WASTE(WATER)!

USING A NATURE-BASED SOLUTION FOR ENGAGING SOCIAL COMMUNITY ORGANIZATION, REDUCING GENDER AND RACIAL DISPARITIES, ENVIRONMENTAL EDUCATION, TECHNICAL INSTRUCTION AND JOB CREATION FOR ENHANCING QUALITY OF LIFE IN BRAZILIAN *FAVELAS*

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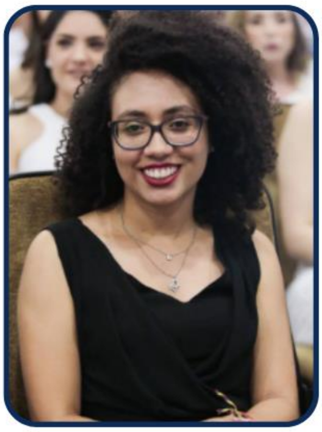
ABSTRACT

Poverty is a multidimensional concept, which includes lack of access to sanitation services, and is more pronounced in developing countries, such as Brazil. In Brazil, especially in São Paulo, the process of urbanization was characterized by accelerated growth with no proper planning and informal settlements, with low access to basic public services such as sanitation. Therefore, as a way of reducing poverty, this project proposes the adoption of a decentralized wastewater treatment system composed of Constructed Wetlands, considered a Nature-based Solution, in combination with Septic Tanks for *favelas* in Brazil. Besides providing people adequate sanitation services, the project involves environmental education, technical training and community participation in all its stages, prioritizing women and/or non-caucasian people, reducing gender and racial disparities and creating jobs.

(p)

THE TEAM



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SUMMARY

1. INTRODUCTION

(a)

(b)

Poverty is not only the lack of financial means for assuring basic life conditions, but rather a multidimensional concept which includes poor health and nutrition, lack of access to sanitation services, deprivation of education psychological trauma and humiliation. In other words, poverty can be described as a general state of mental and physical unhealthy conditions. Hence, fighting against poverty is the number 1 goal of the 2030 the United Nations' Agenda for Sustainable Development (SDG).

Poverty is more pronounced in developing countries. Brazil, the largest Latin American country, presents high inequality, not only in the distribution of income, but also in inequality between genders and ethnicities.

Since poverty consists of a combination of factors and situations, multiple and interdisciplinary solutions are needed in order to tackle it. One way of doing so is through providing people adequate sanitation services, especially when acknowledging that women and people in poverty, living in informal settlements, from certain ethnicities, and people from minorities and discriminated groups are the ones who suffer the most from lacking access to sanitation services.

The process of urbanization in Brazil, especially in São Paulo, was characterized by accelerated growth with no proper planning, which contributed to informal occupation of central, intermediate and mostly peri-urban areas by low-income people. Such settlements are generally addressed as *favelas* and are mainly characterized by precarious living standards and lack of access to basic public services such as sanitation.

With regard to sanitation, the robust infrastructure and high investment needed for the implementation of traditional centralized sanitation systems are the main barriers to attend the population living in *favelas*. Decentralized wastewater treatment systems are a new strategy and a good option for providing sanitation, since they are versatile systems in which wastewater is collected, treated, and discharged (or reused) next to where it is generated, considerably reducing the costs associated with implementation when compared to traditional systems.

This project proposes the adoption of a system composed of Constructed Wetlands, considered a Nature-based Solution, in combination with Septic Tanks as a decentralized wastewater treatment solution for *favelas* in Brazil, using the city of São Paulo as an example. The system is not merely a technology for providing sanitation, but also a tool for social organization, environmental education, reducing gender and racial disparities and job creation.

2. INFORMATION BACKGROUND

2.1. POVERTY

Throughout history, poverty has had different definitions. The first detailed studies of poverty date back to the late 19th century, and over the years this concept has gained new aspects and approaches. Broadly, poverty can be considered as insufficient income for subsistence and participation in the community's lifestyle[1]. However, it is better described as a multidimensional concept, which includes poor health and nutrition, lack of access to sanitation services, deprivation to education, psychological trauma and humiliation[2].

The different definitions lead to different approaches and policies against poverty[3]. Generally, poverty is measured by people living on less than $1.90 a day, and it is estimated that about 783,000 people live in this condition[4]. The global Multidimensional Poverty Index (MPI) assesses poverty through 10 equal indicators divided into three dimensions: health (nutrition and infant mortality), education (years of schooling and school attendance) and standard of living (cooking fuel, sanitation, drinking water, electricity, housing and assets). The results presented in the 2020 MPI report indicate that about 1.3 billion people live in conditions of multidimensional poverty, half of them being children[5].

(d)

Fighting poverty is a global concern, and the number of people living in extreme poverty has reduced from 36% (in 1990) to 10% (in 2015). However, the COVID-19 pandemic could be a risk to this advance, with an additional 75 to 95 million people living in extreme poverty in 2022 compared to pre-crisis projections[6]. The consequences of COVID-19 had a greater impact on those living in poverty and social vulnerability, with a reduction in jobs and higher rates of contamination[7].

Due to its impact on so many people's lives, it is not a surprise that "No Poverty" is the number 1 SDG for achieving peace and prosperity for people and the planet[8].

(b)

2.1.1. POVERTY IN LATIN AMERICA AND BRAZIL

In Latin America it is estimated that about 33% (204 million people) of the population live in poverty and 13.1% (81 million people) in extreme poverty[9]. For children aged 0 to 14 years, 47.2% live in poverty and 19.2% in extreme poverty. In Brazil, 18.4% of the population lives in poverty and 5.1% in extreme poverty[9]. In Brazil, it is estimated that in 2021 12.98% of the population (27.7 million people) live in poverty, which represents an increase of more than 2% compared to 2019, before the pandemic[10].

For a realistic assessment of poverty, income concentration and inequality must be considered. Latin America is characterized by high inequality, not only in the distribution of income, but also regarding gender and ethnicities, aggravated by the COVID-19 pandemic[11]. The Gini coefficient is used to measure the degree of income concentration, indicating the income difference between the poorest and the richest, and its value varies from 0 (absence of inequality) to 1 (maximum inequality). In Latin America, Gini coefficient has an average value of 0.469, and in Brazil it reaches 0.524 (considering the benefits of government social programs)[12,13]. The values are high, indicating high inequality and urgency to reverse this scenario.

Despite significant economic progress, increase in per capita income, inequality and poverty reduction in Latin America in recent decades, there is a significant portion of population that lives in a condition called chronic poverty (about 130 million Latin Americans)[97]. Economic growth is insufficient for these people to leave the condition of poverty, and it is necessary to implement policies that help reversing this scenario.

Chronic poverty is related to a prone context and state of mind, and lack of basic services, such as sanitation. In fact, poverty maintenance in Latin America, despite economic growth, had already been pointed out 30 years ago, due to social inequality[95]. The relationship between economic and political poverty, due to the lack of means for the poor to express their demands is also highlight.

2.2. POVERTY AND SANITATION SERVICES

The SDGs consist of 17 main strategies all interrelated, thus, one has an impact on others. That is the case, for instance, of SDG number 6 which stands for ensuring access and sustainable management of water and sanitation for all. Six out of ten people in the world have no access to safely managed sanitation services, being women, people in poverty, people living in informal settlements, people from certain ethnicities, and people from minorities and already discriminated groups, the ones who suffer the most from lacking access of sanitation services[14,15,16,17,18] Hence, working on providing these groups access to sanitation services contribute immensely not only for diminishing poverty, but also for narrowing gender and social inequities and improving health and life quality of these people.

According to the World Health Organization (WHO), a safe and adequate sanitation service comprises sanitary appliances not shared with people from different households and the treatment of the domestic wastewater either directly or nearby the place in which it was generated or through its collection and transport to a proper treatment facility[19]. Wastewater can be defined as the water that supplies a community after its use in various applications, and is composed of organic matter, nutrients and pathogenic organisms. Thus, the need for collection and treatment for protection of public and environmental health, in addition to the social, economic and political aspects involved [20].

(b)

(e)

The lack of adequate sanitation services is related to waterborne diseases, like diarrhea, especially in low-income economies, besides contributing to cases of malnutrition and aggravating other diseases[19,21,22,23]. It is estimated that diarrhea kills about 1.4 million people a year, and about 297,000 deaths of children under 5 years old, and could be avoided with better sanitation and hygiene conditions[19,24]. Sanitation works as a barrier to contamination, eliminating pathogens and preventing their spread in the environment[25].

Investment in universal sanitation reduces the demand for health services and hospital admissions, besides reducing the number of lost workdays due to medical leave. In 2013, in Brazil, there were approximately 340,000 hospital visits related to cases of diarrhea and vomiting and 50 million lost workdays[24]. Expansion and improvements in infrastructure provide an increase in income and productivity. In Brazil's case, regional and income heterogeneities and universal access to basic sanitation services must be considered, with the adoption of policies that consider regional inequalities[26,27].

Wastewater treatment also reduces the lost school days, increasing children's school performance, and promote better living conditions, dignity and well-being for the population [2,24,28].

Adequate sanitation services also contribute to gender equality. Women and girls have specific demands for hygiene and sanitation, in addition to being responsible for taking care of home, hygiene and health of family members in most places, thus reducing time spent on these activities, women benefit from improvement of these services, having more time for formal jobs [2,29,30,31].

Treated wastewater reduces water bodies' pollution, increases the availability of water for supply, and has potential for reuse, contributing to circular economy[2]. Advances in sanitation universalization promotes environmental, social and economic improvements, which help in various ways in the eradication of poverty[2].


(e)


(e)

2.3. URBANIZATION AND SANITATION SERVICES

Access to sanitation services differs amongst different regions in a country, mostly those living in rural areas having less water and sanitation infrastructure coverage. Howsoever, many of the people without access to sanitation are concentrated in peri-urban areas, living in the poverty belts around or within the cities and representing a difficult and urgent challenge [14,15,16,17,18,32,33,34,35,36,37].

Latin America has a high level of urbanization, with about 80% of the population living in urban areas and home to megacities, such as São Paulo. This disorderly urbanization results in an increase in water demand for supply, wastewater generation and the need for adequate treatment systems, bringing huge challenges to management of sanitation services [2,38].


(f)

In urban areas wastewater is usually collected through pipes, concentrating the polluting load and generating contamination hotspots. The proximity of urban occupations to water bodies and the release of untreated effluents risks the population health. Informal settlements densely populated aggravate this scenario. Environmental issues related to the pollution of water bodies are also of great relevance, and wastewater treatment in urban areas is an urgent issue[39,2,40].

2.3.1. URBANIZATION IN BRAZIL: INFORMAL SETTLEMENTS

Brazil has a high urbanization rate, with 84% of population living in urban areas[41]. São Paulo is the sixth most populous city in the world, with an urbanization rate of 99.1%[42]. In the 2010 census, the city had 11,253,503 inhabitants, population density of 7,398.26 inhab/km² [41].

The beginning of population growth and urbanization process in the region of São Paulo occurred due to the expansion of agriculture, construction of railways and arrival of European immigrants in the early 19th century[43,44], leading to the creation of new urban areas[39]. From the 1930s on, industrialization process intensified, concentrated in São Paulo [45]. The accelerated growth of São Paulo has led to heterogeneous, disorderly urbanization without proper planning, leading to informal occupation of central, intermediate and mostly peri-urban areas by low-income people[46,15,47,44].

The significant increase in urbanization, lack of public policies, economic vulnerability and marginalization of social groups lead to informal settlements around the world[48]. Latin American cities, regarding the accelerated urbanization process, show tendency to become compact (due to the high concentration of inhabitants) and diffuse (due to migrations to occupy peripheral areas)[96]. In Brazil, *favelas* present precarious conditions, without adequate access to basic sanitation services, generally located in areas susceptible to natural disasters, associated with tenure problems and predominantly self-built, being their residents often more exposed to violence and diseases[48,49,50].

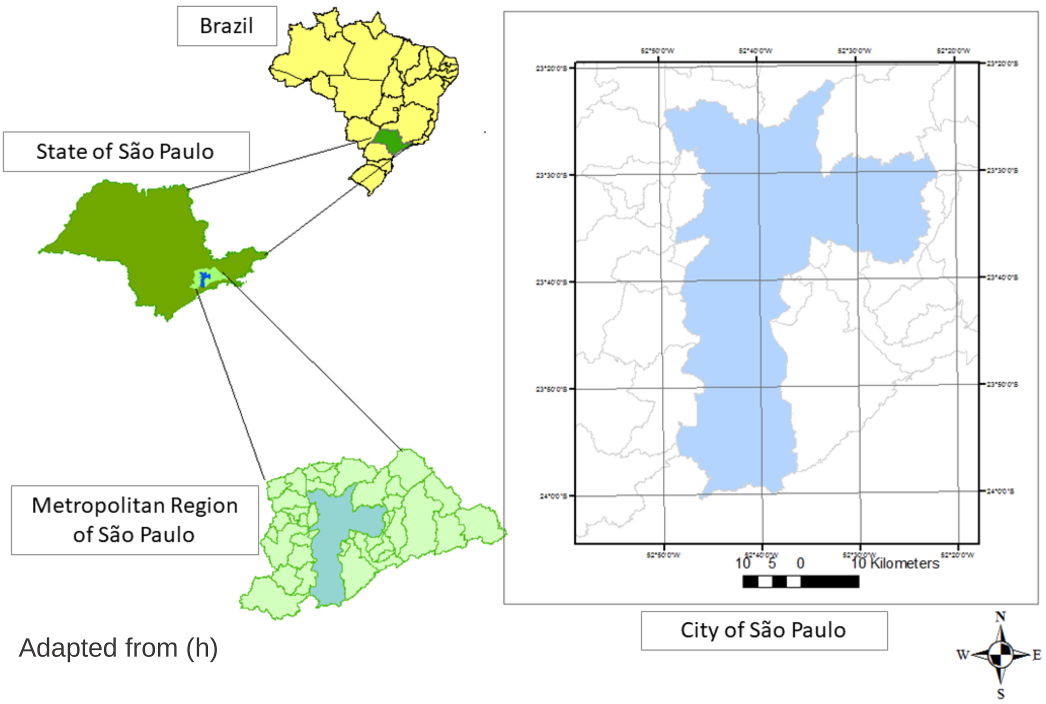
In addition to *favelas*, São Paulo has other irregular occupations with non-conformities in infrastructure and precarious sanitation conditions, occupied by low-income population[51]. Currently, 1,739 favelas are registered in São Paulo, and another 786,991 informal settlements are estimated[51].

A survey carried out in 2010 showed that 11% of the population of the city of São Paulo lived in *favelas* and irregular subdivisions, with 50.8% of this population composed of women, according to the last census carried out in 2010[52]. In relation to the total resident population, 39.3% self-declared as white and 60.7% self-declared as black, brown-skinned, yellow, indigenous or without declaration.

São Paulo's City Management created the *Programa de Urbanização de Favelas*, which consists of transforming *favelas* into regular urban areas and involves implementation of water supply, wastewater collection, public lighting, road improvements, creation of leisure areas and other related activities[53].

Specific research done in São Paulo for identifying access by the poorest parcel of population to urban services, including sanitation, showed that beyond income, many other factors play a role on infrastructure access. Yet, income and living in *favelas* have a big impact on access to sanitation services[18]. Similarly, a study comparing social and spatial determinants of health between formal and informal settlements in the metropolitan area of Rio de Janeiro concluded that people living in informal settlements are poorer, have a lower level of formal education, and are more diverse in terms of skin color[17].

2.4. SANITATION IN BRAZIL AND IN SÃO PAULO



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Basic sanitation services in Brazil are divided in four components: stormwater management, drinking water supply, urban cleaning and solid waste management, and wastewater services or sanitation services[54]. Traditionally, wastewater is collected, transported and treated in Wastewater Treatment Plants (WWTP). In Brazil, adequate sanitation service is defined by the National Basic Sanitation Plan (Plansab) as collection followed by treatment in a wastewater treatment facility or the use of septic tank in its local of generation followed by a post-treatment[54].

Data from 2020 shows that only 50,8% of all domestic wastewater generated is treated[55]. This index does not differ from the global one, which in 2020 accounted for only 54% of the world's population having access to adequate and safe sanitation[56]. Considering 5,570 Brazilian municipalities[41], about 66% of Brazilian municipalities do not have cataloged collective WTPs, and only 3,419 WTPs are identified, distributed in 1,893 municipalities[57].

São Paulo state has the best rates in Brazil regarding wastewater collection, 80.85%, and of the total collected, 86.3% is treated. In São Paulo city, 74.13% of the wastewater generated is collected and 100% of the collected is treated, corresponding to 97% of the urban population served. Despite the good index, the city's concentration of inhabitants rises concerns. Considering the urban population, estimated at 12,214,439 inhabitants, more than 360,000 people are not served by wastewater collection and treatment[55]. The company responsible for managing sanitation services in the city estimates that circa 164,970,600 m³/year of wastewater is untreated, ending up in streams and rivers[15].

The areas unserved by sanitation are mainly informal settlements, occupied by the poorest parcel of the population and usually have rugged topography, high population density and restricted access due to unplanned growth, making it difficult to install conventional sanitation infrastructure, which comprises large pumping infrastructure and extensive pipelines[58,59,15].

The latest review of the city of São Paulo Sanitation Plan (*Plano Municipal de Saneamento Básico de São Paulo*) recognizes the great challenge of providing sanitation services to these areas and acknowledges that the improvements done so far were not sufficient to properly address the urgency. One of the main concerns regards the population that are exposed to sewage, which is the case of many *favelas*. Nevertheless, the document reinforces the commitment to provide access to sanitation to all[15].

Conventional sanitation systems require a significant initial capital investment, besides high maintenance, operational and management costs, leading to financial constraints for expanding attendance, especially in developing countries[37,58]. The infrastructure for wastewater collection and transport in conventional systems is responsible for around 60% of the costs related to wastewater management, highlighting the economic benefits of exploring alternatives that diminish those costs[98].

2.5. DECENTRALIZED WASTEWATER TREATMENT SYSTEMS (DEWATS)

One alternative to address this problem is the use of DEWATS, which is predicted by national law nº 14.026 as a means to reach sanitation universalization by 2033[15,60,61]. In DEWATS, wastewater is collected, treated, and discharged (or reused) next to where it is generated[62,58]. DEWATS are versatile and can be used as a single-family or even as collective treatment solution when organized in clusters or satellite systems. Satellite systems are more appealing in areas with high density of people, usually designed to collect and direct to a treatment facility the wastewater generated by people living inside a 3-km radius, considerably reducing the costs associated when compared to traditional systems[37,63,59,64,14].

Both conventional and decentralized systems must consider economic, social and environmental aspects for its design and be properly operated and maintained. During the last decades many studies have been performed in Brazil regarding DEWATS, most of them focusing on simpler technologies that require non-specialized operation and maintenance and applicability in rural areas, evidencing the lack of proposals for urban solutions[61]. Therefore, this project aims to develop a DEWATS that fits applicability in urban and peri-urban areas unserved by conventional sanitation systems.

2.6. NATURE-BASED SOLUTIONS

According to the International Union for Conservation of Nature (IUCN), Nature-based Solutions (NbS) are defined as actions to protect, sustainably manage, and restore natural or modified ecosystems. Nbs has the purpose of, among others, contribute to economic and social development, improve human health, contribute to water security and prevent environmental degradation[65]. Such outcomes are possible through inclusive, transparent and empowering governance, collaborative planning and implementation.

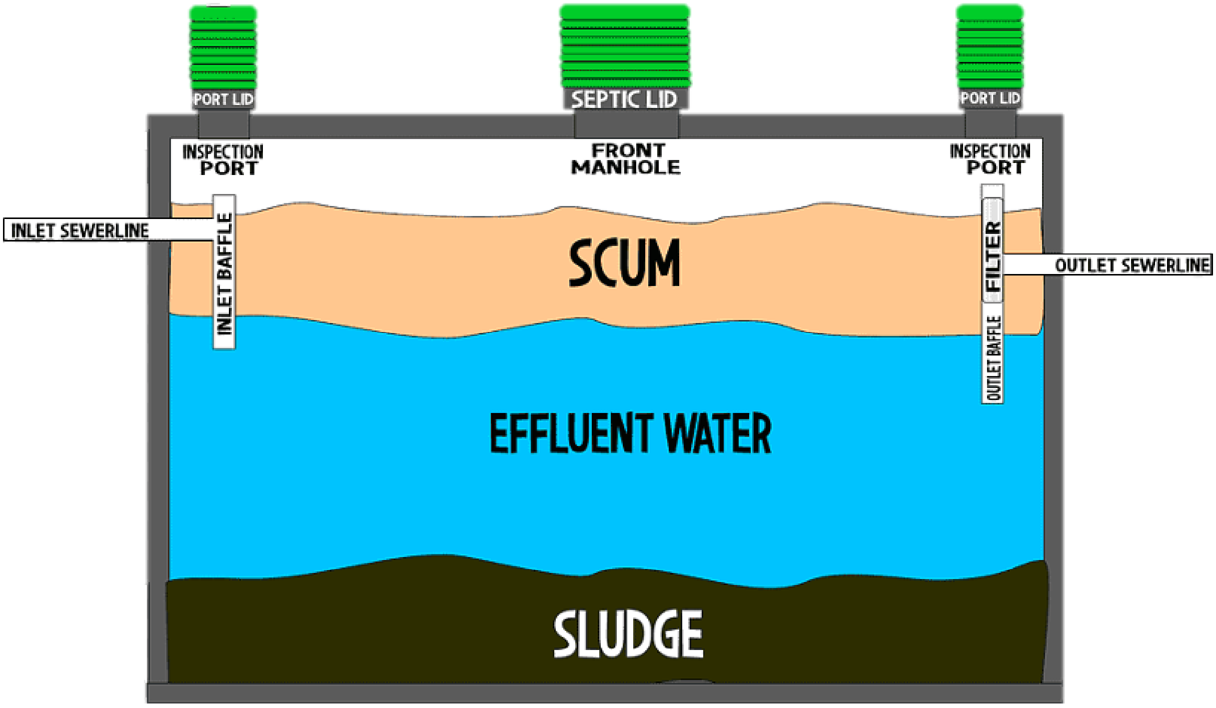
(j)

2.7. DEWATS PROPOSED TECHNOLOGIES

2.7.1. SEPTIC TANKS

Septic tanks are defined as horizontal flow units for wastewater treatment by sedimentation, flotation and digestion processes, and may be composed by a single chamber or more units arranged sequentially[66]. Septic tanks are old and simplified treatment systems, both in terms of construction and operation, so they are still widely used around the world, mainly in single-family homes or areas without the presence of wastewater collection[67,68,69].

The process of treatment involves accumulation of sedimentable solids at the bottom of the tank, forming the sludge layer, and the flotation of oils, greases and other light materials, forming a layer of scum, thus the sewage flows between the layers. The effluent should be referred for post-treatment in order to comply with the Plansab criteria for adequate sanitation[67,54,66,70].



(k)

In septic tanks, the organic matter present in domestic wastewater is processed by anaerobic digestion, through the metabolism of anaerobic microorganisms[20]. Anaerobic processes have significant advantages when compared to aerobic processes, among them: reduced costs of implantation and operation (due to low or zero energy consumption), generation of stabilized sludge in smaller volumes, and combination with other post-treatment methods [71].

In anaerobic wastewater treatment systems (AWWTS), about 5 to 15% is converted to microbial biomass (sludge from the system)[67]. Anaerobic treatment is effective for the removal of biodegradable organic components, so they can be used not only in domestic wastewater. However, the removal of nutrients (nitrogen and phosphorus) and pathogens is insufficient, thus the importance of post-treatment for meeting environmental requirements[67,72].

There is, however, resistance to the use of anaerobic systems mainly due to the possibility of odor emanation and the reduction of treatment efficiency when exposed to abrupt changes in process or operational conditions[73]. Nevertheless, anaerobic systems have been increasingly improved for treating large volumes of wastewater and are also considered interesting alternatives for the treatment of small wastewater volumes[74,75,76].

As an example of successful application of AWWTS, the Brazilian Ministry of Agriculture, Livestock and Food Supply (MAPA) created Brazilian Agricultural Research Corporation (Embrapa) to develop technological options based on characteristics of Brazilian rural communities. Embrapa has been working with simple and efficient technologies, which require few inputs, use common materials, present affordable installation and maintenance costs, are simple to operate and adapt well to the routine of the rural property[77,94].


(I)

To encourage the installation and facilitate the dissemination of the technologies, explanatory materials such as leaflets are available for residents of the communities. This model was developed with a focus on rural communities, however, the similarities with urban communities allow it to be adapted and replicated. Currently in Brazil there is no equivalent federal institution for developing technological options aiming at applications in highly urbanized areas.

2.7.2. CONSTRUCTED WETLANDS

Constructed Wetlands (CW) are considered NbS, consisting of engineered systems designed to improve natural treatment processes. CW are considered sustainable options for domestic wastewater treatment, presenting low operational and maintenance requirements[78,79,80]. CW with subsurface flow can function either on a vertical or horizontal flow. Both configurations require previous primary treatment for preventing clogging.

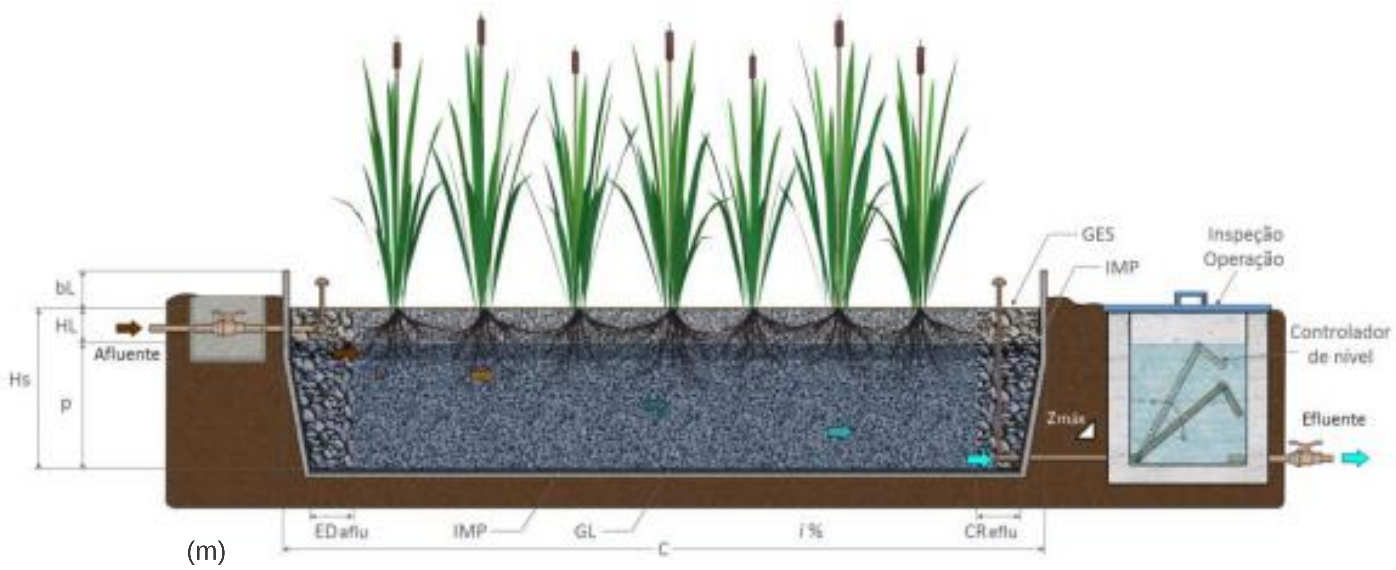
There are three main components in CW: porous medium, macrophytes (plants) and microbial community. The treatment is a result of physical, chemical and biological interaction of these components, leading to many reactions and removal pathways occurring simultaneously in the reactor.

A large variety of emergent plant species (the roots stay in the porous medium while the leaves are above the water level) can be used in CW. The main criteria for the selection are the type of CW and the adaptation of a given species to the local climate. The plants' roots provide the environment for the growth of a diverse consortium of microbes and bacteria, so called biofilm, that perform both anaerobic and aerobic processes in treating the wastewater. The plants also provide oxygen for the porous medium and promote scenic beauty[78,79,80].

The porous medium is usually gravel and it functions as support for the plants and for the establishment of biofilm, and as a filter for retaining suspended solids. Different sizes of gravel are used for enhancing the hydraulic flow within the CW and preventing clogging, which is the most problematic issue in CW for limiting contact area and time between the sewage and the biofilm. A good operation of the primary treatment is essential for preventing excess solids to reach the CW and thus prevent clogging, also, building the system with a bottom slope up to 1% helps enhancing the hydraulic flow[78,79,81,80].

The biofilm is composed of bacteria, fungus, protozoa and metazoa, that will develop adhering to the plants' roots and the porous medium material, being responsible for degradation of organic matter, nutrients such nitrogen and phosphorus, and for the predation of pathogenic organisms, promoting disinfection of the wastewater[78,79,80].

The water enters the system at one end being evenly distributed and flowing through the porous media to a standpipe for discharging. It is important to isolate the system to the surrounding soil by a combination of a plastic liner and geotextile membrane[78,79,81,80].



(m)

As mentioned, both anaerobic and aerobic processes take place in CW, but they are generally designed as aerobic systems. Aerobic wastewater treatment is widely used all over the world, and has high efficiency, with the removal of 85 to 95% of the organic load. However, about 30 to 40% of the organic matter is converted into microbial biomass, which becomes the excess sludge of the system[67], increasing their operating costs. To enjoy the benefits of aerobic treatment while reducing its disadvantages, it is interesting to allocate them as a post-treatment system for anaerobic effluents[67].

(n)

(o)

3. THE PROJECT

(p)

Given the scenario presented in the previous topics, it is evident that sanitation services for informal settlements is an effective way to reduce poverty and inequality not only in Brazil. Due to the characteristics of the settlements, decentralized systems (DEWATS) are advantageous possibilities, which enable adequate sanitation and allow the participation of the population. The proposal of this project is a compact wastewater treatment system, to serve the population of informal settlements, through a combination of septic tanks and constructed wetlands (anaerobic + aerobic treatment), to guarantee the efficiency of the treatment, easy installation and low-cost operation.

For this project, it was defined that the target group/area would be informal settlements in Brazilian urban areas, represented by the city of São Paulo, and each module of the projected system has the capacity to serve up to 30 people. However, the same technology can be applied in other communities around the world and installed in a greater number of modules.

For the implementation of the proposed system some minimum requirements were acknowledged. A checklist that summarizes the main items needed is presented, which must be applied to each community. However, the absence of one or more items does not imply the impossibility of implementing the project, and it only means that requirement must be developed before the execution of the system itself or that the project must be adapted to the specific conditions of the community, with small modifications.

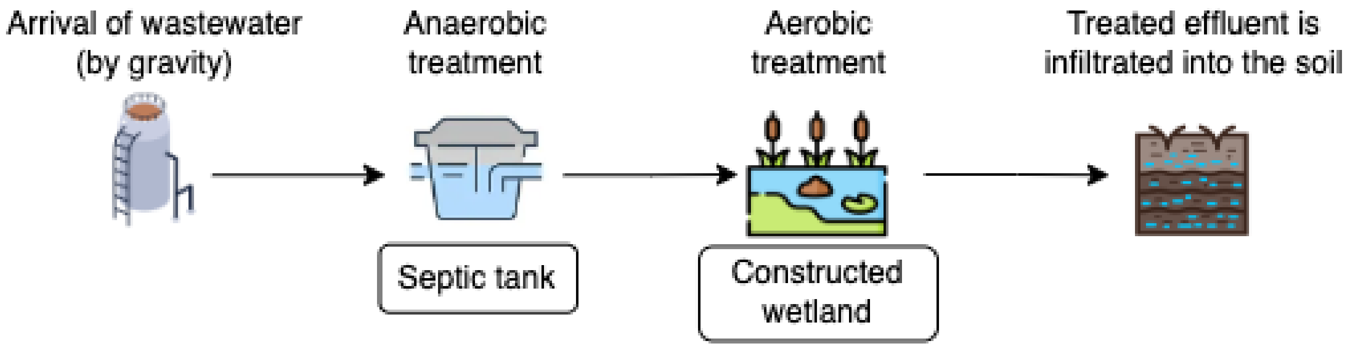
Informal settlement characteristics - Checklist:

- ✓ Community located in urbanized area
- ✓ Location with humid tropical climate (or similar)
- ✓ Absence or deficit of wastewater treatment system
- ✓ Existence of wastewater collection pipes in dwellings
- ✓ Availability of enough area for system implementation
- ✓ Existence of a residents' association
- ✓ Existence of community women's organization

To ensure the proper functioning of the system, periodic maintenance and proper operation must be performed. The objective of this project is to ensure community involvement in the entire wastewater treatment process, from its construction to its maintenance. Therefore, the idealized system is simple to implement and operate by the local residents after basic technical training.

3.1. LET'S TALK SOME TECH

The flowchart below illustrates the stages of the wastewater treatment system.



3.1.1. CONSTRUCTIVE ASPECTS AND DESIGNING OF THE SYSTEM

SEPTIC TANKS

In Brazil, the design, construction and operation of septic tanks is regulated by the technical norm NBR 7229[66]. The main issues addressed are:

- Minimum distances: Septic tanks must be installed more than 1.5 m from any construction, more than 3.0 m from trees and public water system and 15.0 m from water bodies.
- Materials: All materials used in the construction of the tanks must have mechanical and chemical resistance to the substances present in the sewage and must guarantee stability related to possible horizontal and vertical loads in the area. Tanks must be impermeable.
- Dimensioning: The number of contributors must be considered, to estimate the flow; minimum detention time between 12h and 24h, depending on the daily

volume of effluent; the contribution of fresh sludge, calculated according to the number of contributors; and the total sludge accumulation rate, which varies with temperature and cleaning frequency.

- Internal measurements: The useful depth of the tank varies between 1.20 and 2.80 m, according to the calculated volume; the internal diameter must always be greater than 1.10 m.
- Input and output devices and at least one inspection opening in each tank must also be provided, according to NBR 7229.

The dimension of the septic tank will be presented according to NBR 7229[66]. The total useful volume of the tank must be calculated by Equation 1.

$$V = 1000 + N\,(C * T + K * Lf) \quad \text{(Equation 1)}$$

where: V is the useful volume (L), N is the number of inhabitants of the place (inhab), C is the individual daily contribution of wastewater (L/inhab.day), T is the detention time (days), K a digested sludge accumulation rate (days) and L_f the fresh sludge contribution (L/inhab.day).

A population of 30 people (N) will be considered, a wastewater contribution of about 130 L/inhab.day (C) and 1 L/inhab.day of fresh sludge (Lf), totaling 3900 L/day of wastewater to be treated in the system. For this flow range, the standard suggests adopting a hydraulic retention time of 20 hours, 0.83 days (T). Because of the climatic conditions in Brazil and other Latin American countries, an average temperature above 20 ºC can be considered. Adopting an annual cleaning frequency, the standard recommends using a value of 57 days for the sludge accumulation rate (K).

$$V = 1000 + 30\,(130 * 0{,}83 + 57 * 1)$$

$$V = 5{,}947\ L$$

Thus, the useful volume of the septic tank must be 5,947 L, or 5.95 m³.

In this project it is recommended to use prismatic tanks to facilitate the excavation and construction process. For tanks up to 6 m³, the minimum useful depth is 1.20 m and the maximum is 2.20 m. The length/width ratio must be a minimum of 2:1 and a maximum of 4:1. Therefore, it was defined that the septic tank will be built with a depth of 1.5 m, 4 m in length and 1.2 m in width, totaling 7,200 L of volume. The useful depth is about 1.25 m.

The inlet and outlet pipes of the tank must be formed by T connections (fig. k) The tank must have two upper inspection openings, with a radius of 0.6 cm, which allow cleaning procedures to be carried out. The openings must be positioned close to the inlet and outlet pipes.

CONSTRUCTED WETLANDS

Currently there is no technical norm regarding the design and construction criteria for CW, but researchers from Brazil produced a document compiling national and international information about the use of CW as a decentralized collective system for treatment of domestic wastewater previously treated by septic tanks or other technologies. Von Sperling & Sezerino (2018) presents designing criteria for CW projects adapted for the climate conditions in Brazil, besides listing of plants and medium materials, operational and maintenance needs and expected treatment efficiency. The following information refers to the mentioned document.

- Height of porous medium: 0.5 to 0.9 m. The wastewater level within the CW must be a minimum of 0.10 m below surface.
- Length x width: 2:1 up to 4:1. These values can be modified in function of the project and land specific characteristics.
- Number of parallel units: having more than one unit operating in parallel is advised for operational flexibility during maintenance and cleaning, but it is not mandatory.
- Bottom slope: 0 up to 1% for enhancing the hydraulic flow and preventing clogging. It is important to mention that the slope must be applied only to the bottom of the system. The surface of the CW must be leveled.
- Size of the porous medium: for the inlet and outlet zones gravel from 50 to 76 mm must be adopted. In other zones smaller sizes can be used. Smaller sizes of gravel promote better filtration but on the other hand, clogging is facilitated.

Therefore, the choice of gravel size must consider the hydraulic performance and the amount of solids coming from the primary treatment.

- Inlet and outlet system: is usually made through regular plastic pipes with holes in it. They usually stand in the porous medium (gravel) to avoid the exposure of wastewater over the surface, to prevent bad odor release and to not attract insects.
- Impermeabilization: it is important to isolate the system from the surrounding soil. CW walls and bottom are usually made of concrete or cement, but it is also possible to use plastic liner or textile membranes.
- Plants: a large variety of plant species can be used as long as they adapt to the local climate conditions. The plants might also be selected considering their landscaping potential for providing the system a more beautiful appearance contributing to a more pleasant look of the surroundings. Usually 4 plants are planted for each square meter of w CW. With time the plant biomass will grow and develop, thus requiring some maintenance.

For the purpose of this project, a simplified methodology for designing a CW will be considered. For a more detailed approach, please refer to Benassi (2018) and Von Sperling and Sezerino (2018). For the design of a CW treatment it is necessary to consider the organic load entering the system. For the raw sewage the organic matter concentration (or BOD - biodegradable oxygen demand) of 300 mg/L is going to be considered. Equation 2 is used to calculate the total organic load based on the sewage volume coming from the Septic Tank.

$$SOL = ASF * OMC \text{ (Equation 2)}$$

where: SOL is the sewage organic load (g/day), ASF is the average sewage flow (L/day) and OMC is the organic matter concentration in the sewage (g/L).

$$SOL = 3900\ L/day\ x\ 0{,}3\ g/L$$

$$SOL = 1170\ gBOD/day$$

The organic load entering the CW is calculated by Equation 3. The organic load removal efficiency of 50% is considered for the previous treatment in the Septic Tank.

$$OL = SOL * \ (1 - \frac{RE\ SP}{100}) \quad \text{(Equation 3)}$$

where OL is the organic load entering the CW (g/day) and RE SP is the removal efficiency of the septic tanks (%).

$$OL = \ 1170 \frac{gBOD}{day} * \ (1 - \frac{50}{100})$$

$$OL = 585\ gBOD/day$$

The next step is to calculate the required superficial area for the CW by adopting a value for the superficial organic load application. We will adopt 15 gBOD/m².day. Equation 4.

$$RSA \ = \frac{OL}{SOLA} \quad \text{(Equation 4)}$$

where RSA is the required superficial area (m²) and SOLA is the superficial organic load application (gBOD/m².day).

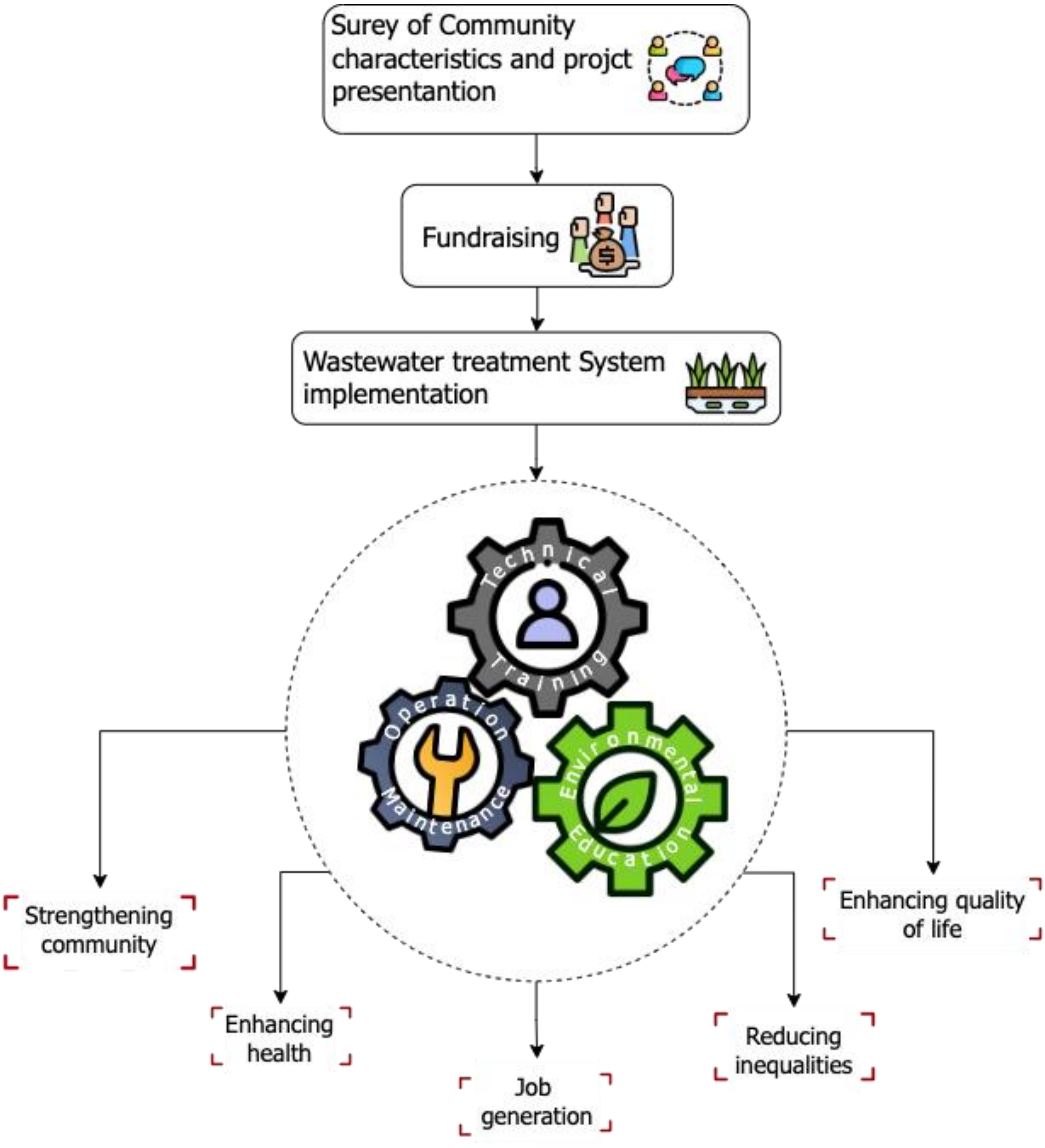
$$RSA \ = \frac{585\ gBOD/day}{12\ gBOD/m^2.day}$$

$$RSA \ = 48{,}75\ m^2$$

Considering the recommended length x width ratio of 2:1 up to 4:1, a CW of 2,5m x 20m will be adopted.

3.2. BEYOND TECHNICALITIES

The system proposed is not merely applied as technology for providing sanitation, but rather used as a tool for social organization, environmental education, reducing gender and racial disparities through contemplating the NbS principles of inclusive, transparent and empowering governance, and collaborative planning and implementation. It also takes in consideration the human rights-based approach, in which groups that are historically left behind due to discrimination or unequal access to both resources and opportunities are encouraged to take part in decision-making processes[14].



(q)

3.2.1. ENGAGING SOCIAL COMMUNITY

In many *favelas* in São Paulo the population is already organized in groups for community management so called as Residents' Associations (RA). The idea is to take advantage and improve such existing structures, making them more inclusive.

Gender equality and women's empowerment is the 5th SDG, and the creation of women's committees or community councils are interesting structures to create spaces for dialogue and qualification that increase the participation of women in these community groups.

Initiatives that aim to discuss feminist and intersectional perspectives in the design and management of cities in Brazil as "Gender and Cities: Practical and Intersectional Guide for More Inclusive Cities" analyze urban planning through the integration of different characteristics of citizens such as gender, race, sexual orientation, age and physical condition.

Urban spaces are diverse and complex, respecting particularities of each community is a determining factor for the project success. The involvement of residents in all stages of design, construction, operation and maintenance is what makes its implementation feasible. With this, the transformation of space as well as of the social function allows a re-signification of women, removing them from the concept of inferiority and fragility typical of specific social classes[82].

Based on these concepts, the RA will be involved in deciding the best places for implementing the system and for assigning groups that will be responsible for the system construction, operation and maintenance. When the people from a given community learn about and start to exercise their rights, and are empowered to participate in the decision-making process regarding issues that affect them, they can help to ensure that their needs will be respected, and the transforming power of such actions increase when people in disadvantage or in vulnerable situations are included in such process[14].

This participation can be used as a social management instrument and, together with education, lead to changes in habits, practices and attitudes, knowledge building and sharing, as a result of collective construction in search of improving the quality of life. Thus, individuals, families and the community, sensitized and trained, are able to identify, analyze and collaborate effectively in the solution and/or referral of problems[83].

3.2.2. REDUCING GENDER AND RACIAL DISPARITIES

Focusing on minimizing disparities, a group of people together with the RA, will be assigned to be responsible for the construction and implementation of the DEWATS, and a second group will be assigned for the operation and maintenance of the system. The groups will be composed of residents and will preferably be women and/or non-caucasian people in order to give a chance for those whose society historically denied opportunities.

(r)

(s)

3.2.3. ENVIRONMENTAL EDUCATION FOR SUSTAINABILITY + TECHNICAL INSTRUCTION AND JOB CREATION

The success of the proposed project depends not only on the dimensioning and constructive aspects of the implemented system, but also on the training of the population for its operation and maintenance. Therefore, it is essential that the implementation plan includes a program of environmental education for the community that will receive and operate the wastewater treatment plant. Involving, educating and engaging the community is critical for guaranteeing the project's long-term success.

The International Labor Organization recognizes that combining the local community participation and involving both skilled and unskilled people for performing work, and the adoption of adequate technologies is an economically viable way to infrastructure works and create jobs. It also points out that providing local people proper capacity training and giving the opportunity to work promotes experience in negotiating and organizing, thus empowering the community[85].

Environmental education aims to engage the population in environmental issues, providing new ways of thinking, acting and making decisions that consider the environment. Environmental education programs are mainly developed in schools (formal education) but can also be carried out in communities and leisure places, including different age groups, bringing social, environmental and economic benefits, mainly in economically and socially vulnerable communities[86,87].

In this project, it is proposed to implement an environmental education program focused on sanitation through the presentation of seminars for the members of the RA and the assigned construction and operation groups. The seminar will be divided into two main parts. The first part regarding the importance of the system for the environment preservation and the residents' health, the presentation of general concepts and basic functioning of the system and notions related to wastewater treatment. The second part regards the technical training for the community members assigned to operate the wastewater treatment system. The two parts must occur in a parallel and continuous way, with the community itself being responsible for the continuity and renewal of the program. The main topics covered in the program are described below.

1st Part: Covering the basics and engaging the community

For the first phase of the education program, the RA members will take part in seminars/workshops presented by experts. In a second moment, the RA itself will be responsible for presenting the seminar to other groups of residents in order to involve the whole community in.

TOPICS COVERED:

- General concepts related to the environment:
    - The importance of nature, water resources and the need for preservation;
    - Pollution and its consequences;
    - Actions that pollute the environment;
    - Daily actions that can help preserve the environment.

- Definitions of initial concepts related to sanitation:
    - What is wastewater and what is its general composition;
    - Why it is important to treat wastewater and what are the consequences if there is no treatment;
    - Relation between sanitation and health.


(b)

2nd Part: Training the community operators of the system

The ones assigned to be part of the operations and maintenance group must receive proper technical treatment in order to be able to perform their task. The training must be given by professionals from the sanitation sector.

Having received the proper training and acquired experience operating the system, the people from the operations and maintenance group might feel confident to seek further training and education and perhaps be able to apply for jobs outside the community. The seek for further education must be encouraged. Then, the free spots in the group must be filled by other members of the community interested in learning and working on the project, guaranteeing its sustainability.

TOPICS COVERED:

- Wastewater Treatment Plants:
    - Simplified concepts of wastewater treatment (microorganisms, decomposition of organic matter, pollutant load);
    - Good practices to guarantee the operation of the wastewater treatment plant.
- Importance of using personal protective equipment;
- Security measures for system operation and maintenance actions;
- Procedures to be performed and frequency;
- Parameter evaluation and simple troubleshooting.

3.2.3.1. Technical Training - Operation and maintenance of the system

It is reinforced that there should be no contact with the effluent without proper personal protective equipment and adequate training. Maintenance consists of simple procedures that will be described below.

SEPTIC TANKS

For septic tanks, due to the sizing of the system, an annual removal of sludge and scum must be carried out. The total scum and about 90% of the digested sludge must be removed, keeping 10% of the system. Septic tank sludge due to the anaerobic process, it can have an unpleasant odor[88].

Removal is done through the inspection cover and the operator must wear a protective mask, boots and rubber gloves. Initially the lid must be opened to release the gas, then the sludge and scum must be removed with a suction hose. The destination of the digested sludge depends on the guidelines of the agency responsible for sanitary wastewater in the place. The sludge generated in the Septic Tanks (primary treatment) must be addressed to a proper treatment facility. The responsibility for the sludge collection, management and final destination would fall under the public administration of the municipality/county for assuring proper management and having the financial means of the logistics process.

CONSTRUCTED WETLANDS

The operation and maintenance of CW are simple, consisting of checking the conditions of the pipes and “gardening” the plants.

- The pipes must be checked every 5-15 days.
- Weeds that may eventually grow must be removed.
- The CW plants must be pruned every 20-30 days. The time will vary depending on the species of plant and the local conditions. Also, the number of plant individuals must be controlled in a way that the plants don’t occupy more than 50% of the superficial area of the CW (the older individual must be harvested when the plants are occupying more than 50% of the area).
- If clogging is observed in the pipes, it may be considered changing them for ones with larger diameters. If clogging is observed in the CW, usually it is

related to the operation of the primary treatment which is in our case, the Septic Tanks. In this case, the need for sludge and/or removal must be verified.

Before

After

Before

After

3.3. FINANCING

Wastewater is still an undervalued resource, however, proper management can provide not only environmental, but also social and economic benefits, creating opportunities for sustainable development and a circular economy[2]. In fact, under the concept of New Sanitation, which is perceived as a trend in the sanitation sector, wastewater is a resource to recover nutrients, energy, and of course water, thus contributing to a sustainable water management[89,90,91]. Therefore, the funding for the proposed project is an investment, not only in the environment, but in the community that lives in these irregular settlements.

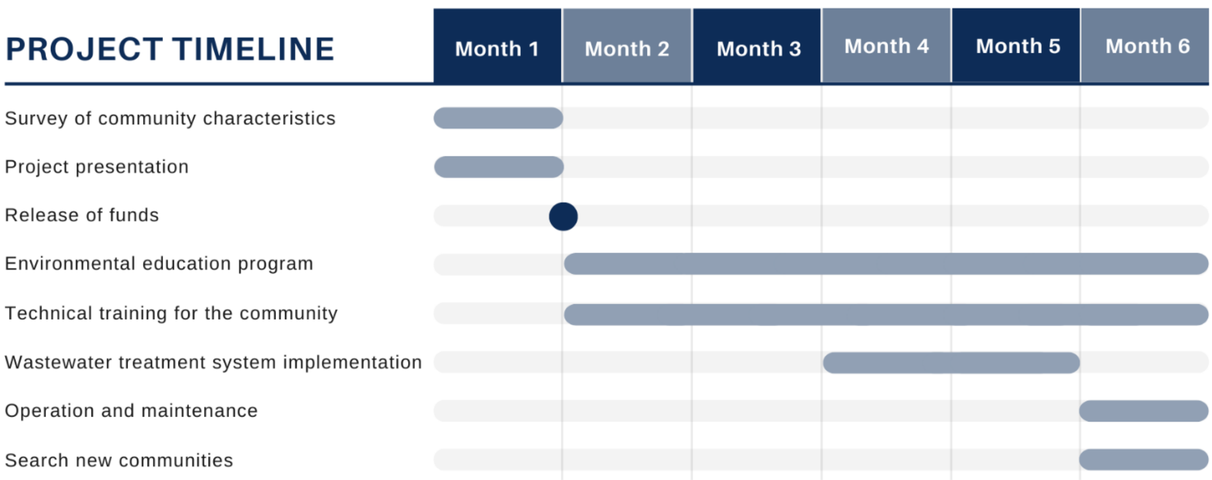
In Brazil, wastewater treatment in urban areas is the responsibility of the government, and the Municipal Sanitation Plan of São Paulo already plans the mapping of areas where it is possible to adopt decentralized systems, as well as technical training and environmental education to sanitation, being this last one focused on public sectors managers[92]. In our proposal, the technical training would be extended to members of the organized civil society represented by the group defined by the RA for operation and maintenance of the treatment system of the community.

The government also makes the commitment to encourage new management models for increasing civil society participation in decision making and initiatives that contribute to environmental awareness. Therefore, the project presented is adequate to the proposals and planning of the Municipal Plan and would be able to receive government funding. For other cities, the appropriate circumstances must be evaluated.

Assuming the involvement and commitment of civil society, the community group leading the project should also feel free to discuss other sources of funding apart from the government, as far as the community group responsible for managing the project/treatment system is free to decide how and where to apply the funding, allocating the resources toward their own priorities and needs.

3.4 PROJECT TIMELINE

The following timeline presents an estimate of deadlines for the implementation of the project. It is reinforced that the environmental education program and technical training must be continuous, as well as the maintenance and operation of the system after its execution.



3.5. THE DREAM IS NOT SO FAR - SUCCESS CASE

Like what is proposed in this project, the community of Vale Encantado, in Rio de Janeiro, Brazil, implemented a wastewater collection and treatment system for about 100 local residents. The community was founded in the 19th century, and since 2005 it has become a destination for sustainable tourism, therefore, the concern for the environment and the well-being of the population led the residents' association to seek solutions for the generated wastewater. In 2021, with the support of investors and researchers, the system was completed, which is composed of an anaerobic biodigester and the reuse of biogas. This case shows the viability of installing the system and including the population in the project. However, it took about 15 years (from 2006 to 2021) for the community to receive wastewater treatment, an essential service that has consequences for the health of the population, the local economy and environmental preservation. This highlights the urgency of projects that enable and accelerate the implementation of wastewater treatment systems in informal settlements, not only in Brazil, but throughout the world[93].

(v)

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