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Evapotranspiration tanks for blackwater treatment in a community settlement of Izidora Stream Basin in Brazil

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Abstract - Disorderly urban expansion directly impacts city planning, a phenomenon that induces the settlement of vulnerable populations in areas lacking urban planning. Located in the northern sector of the city of Belo Horizonte (Brazil), the Izidora settlement has become established in the largest preserved fragment of the Atlantic Forest in the city, resulting in deforestation and degradation of riparian areas, affecting the region's watercourses. The Vitória Settlement, located in the Izidora region, is home to 4,500 low-income families. Due to the deficient urban infrastructure and buildings lacking a sewage system, domestic sewage is discharged directly into the watercourses, impacting the quality of aquatic ecosystems. In 2021, the Vitória Settlement was rehabilitated, aiming to restore the water bodies and their riparian forests. Among the recovery interventions, 12 Evapotranspiration Tanks (TEvaps), a nature-based and low-cost wastewater treatment system, were installed. These TEvaps promote the treatment of blackwater using microorganisms capable of decomposing organic matter, combined with plants that facilitate the elimination of water into the atmosphere through transpiration. This study evaluates the results of the TEvaps installed in the settlement through biological, physical, and chemical parameters of water samples collected from the region's watercourses.

Keywords: TEvap, wastewater treatment, water conservation, pollutant removal, black water

1. Introduction

The urban expansion process is marked by social inequality, which impacts various aspects of urban planning. With urban expansion, the poorer classes were unable to establish themselves in urbanized areas, forcing them to settle in the peripheric areas which largely lack a formal development planning [1]. The Izidora settlement (Fig. 1) located in Belo Horizonte city (Brazil) is the largest urban settlement in South America was constructed within a watershed tributary of the São Francisco River. The area constitutes the largest preserved fragment of the Atlantic Forest biome within the city of Belo Horizonte (19°48'53.58"S, 43°54'52.09"W), covering 950 hectares with around 280 springs. However, this region has faced the establishment of an informal settlement by low-income populations, resulting in deforestation and degradation of this region. In consequence, there occurred the degradation of riparian areas and severe impact to the watercourses. [2].

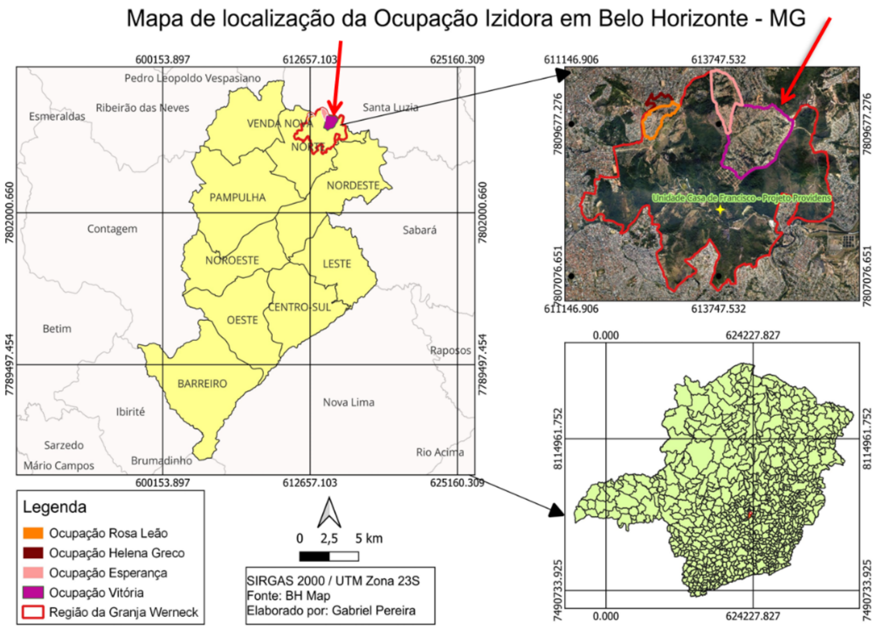

Fig. 1: Location Map of the Izidora Occupation in Belo Horizonte

The Vitória Settlement is located within the Izidora area, hosting around 4,500 low-income families. This settlement is connected to four main watercourses that are tributaries of the Macacos Stream (Fig. 2). Due to the deficient urbanization process, poorly planned buildings, and lack of sewage systems, waste is being directly discharged into the watercourses, which directly impacts the quality of the aquatic ecosystem. According to the sanitation data provided by the BHMap, the region most lacking in sewage systems are the northern areas of the city, including the Izidora Stream Basin [3].

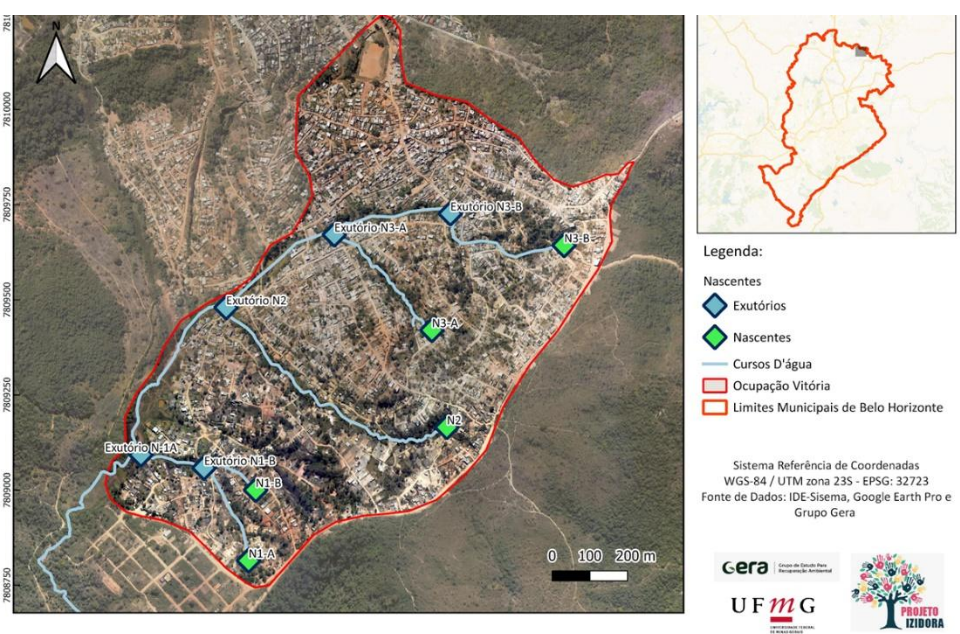

Fig. 2: Location Map of the Vitória Settlement

According to the joint monitoring programme for water supply and sanitation (JMP), 4.5 billion people currently are not provided with managed sanitation [4]. Within this context, the separation of blackwater (BW) and greywater at the source is a wise choice. Blackwater is the fraction of domestic sewage originating from the toilets. Despite it is produced in a much lower volume, it contains the highest fraction of pathogens and nutrients than the greywater [5]. The total amount of faeces excreted by a human along one year was estimated in 25 to 50 kg, containing in average 550 g of nitrogen, 180 g of phosphorus and 370 g of potassium [6]. The urine produced by an adult was estimated 400 L of urine per year, containing 4 kg of nitrogen, 400 g of phosphorus and 900 g of potassium. Considering that the Vitória Settlement hosts 4.500 families or around 8.000 people, the sewage load carried by blackwater may be considered very high.

Managing wastewater is a significant environmental challenge, especially in regions where conventional sewage systems are impractical or unavailable. A possible solution to address the lack of sanitation measures provided by the government is the implementation of nature-based alternative sewage systems, such as septic tanks and soak ways, Residential Wastewater Treatment Plants, or Evapotranspiration Tanks (TEvap).

Evapotranspiration tanks are an innovative solution used in wastewater treatment, especially in areas where conventional systems may not be viable. They provide an ecological and cost-effective alternative to traditional septic systems, reducing reliance on water-intensive sewage treatment processes and minimizing the risk of groundwater contamination [7]. The evapotranspiration tank (TEvap) is a simplified treatment system, aiming at zero liquid discharge, which can be used for blackwater treatment at household level. It is a soil and plants-based system. TEvap are concrete chambers that receive sanitary sewage directly from the toilet. This tank is filled with one or more layers of different substrates as tires, stones, bricks, sand, gravel, and soil in a sealed and impermeable system. In the upper layer, banana plants are planted (Fig. 3). Microorganisms in the fecal organic matter are confined within the system, and in this anaerobic environment, the decomposition of all organic matter occurs. The mineralized nutrients are absorbed by the plant roots, as well as the sewage water. Through plant transpiration, all the sewage water is used and exchanged into the atmosphere [8]. Thus, nutrients are incorporated into the plant biomass and the water is eliminated through evapotranspiration, without runoff. As a result, there is no soil pollution or risk of soil contamination [9].

Fig. 3: Evapotranspiration System (TEvap) using concrete chambers filled with stones, tires, sand and soil that receive the sanitary sewage. Banana plants (Musa sp) are responsible for nutrient absorption and water transpiration.

As shown in Fig. 3, the primary structure of the TEvap [10] consists of a durable and waterproof tank made of reinforced concrete or polyethylene. This tank is divided into two compartments: a sedimentation chamber for the initial treatment of wastewater and a treatment chamber where the evapotranspiration process occurs. The construction includes, in addition to stones and tires, a system of perforated pipes to evenly distribute wastewater throughout the soil layer. This ensures that all areas of the tank are utilized in the treatment process. On the top of this structure, it is placed the following materials:

A) A soil layer composed of a selected soil mixture with a good water retention capacity and drainage properties to facilitate the evapotranspiration process. The soil layer typically consists of a mix of clay and sand to optimize moisture balance.

B) A gravel Layer installed to improve drainage and support the soil, preventing blockages and ensuring the distribution of wastewater.

C) Hydrophytic Plants: these plants are crucial for the transpiration process, where they absorb water through their roots and release it into the atmosphere through their leaves.

The design of the TEvap is adapted to local conditions, including climate, soil type, and the volume of wastewater generated. The size of the tank and the depth of the soil and gravel layers are calculated based on these factors. The tank is usually installed underground or partially buried, with its upper surface integrated into the landscape (Paulo et al. 2019). The regular monitoring of the system is essential to ensure its proper functioning which includes checking the plant health, soil moisture levels, and the integrity of the distribution pipes. Maintenance activities may involve replanting vegetation, adding soil, or unclogging pipes as needed

In 2021, the rehabilitation of the Vitória settlement was performed aiming at re-constructing the degraded drainage systems and the riparian forests [2]. Among the recovery interventions, 12 TEvaps (Figure 3) were constructed in the N1 area (Figure 2). In this study, we aim to evaluate the effectiveness of these TEvaps on the quality of water in the recovered drainage systems.

2. Materials and Methods

2.1- Construction of TEvaps

The installation of 12 TEvaps was carried out along the reconstructed watercourse and the recovered riparian forest of N1, both on the right and left margin of the drain. The following criteria were used:

1 - Selection of Benefited Residences along the N1 Drain: Houses located outside the Permanent Preservation Areas (PPA), since the Brazilian Forest Code [11] prohibits the construction of facilities less than 15 meters from the watercourse. These houses should have a low slope to facilitate the excavation and installation of the TEvap, and the local resident should be interested in installing it.

2 - Sizing and Excavation of the Tanks: for the excavation, a useful volume of $2m^3$ per tank was adopted for each residence, considering 4 adults per house. The dimensions of the tank were 2 meters in width, 1 meter in depth, and 4 meters in length.

3 - Construction Technique: Cemented chamber providing greater structural resistance with a waterproofing additive and concrete at the bottom, ensuring the containment of effluent in the system. Inclusion of tires in the anaerobic chamber covered with stones. Additionally, a piezometer was installed, penetrating the tire chamber, and a 50mm diameter drainage pipe was placed 10cm below the soil at the tank's outlet to prevent overflow. Layers of 10cm gravel, 10cm sand, and 35cm soil were then added up to the upper limit.

4 - Banana Plants: 3-4 small banana plant seedlings were planted in each system.

2.2- Assessment of the effectiveness of the installed TEvaps.

The effect of installing the 12 evapotranspiration tanks on the recovered drainage in area N1 (Figure 2 - arrow) was assessed through water quality. Water samples were collected from both the preserved and impacted sections of the Macacos stream, the latter having a significant sewage inflow at the confluence with the Stream Izidora. These preserved and impacted sections were used as positive and negative controls, respectively. Analyses were conducted during both dry and rainy seasons. One year after the installation of the TEvaps, water samples were collected upstream and downstream the N1watercourse where the tanks were installed (Fig. 4) which were analyzed in triplicate. Sample collection, handling, and preservation, as well as analyses, were carried out according to the methods specified in the "Standard Methods for the Examination of Water and Wastewater," edited by the American Public Health Association [12].

For the assessment of water quality, the physicochemical variables were determined., pH, temperature (°C), conductivity, Phosphorus ($PO4^-$), total nitrogen (total N), Ammonium, biochemical oxygen demand (BOD) and total Coliforms.

3- Results

The results presented in Table 1 show that the main parameters affected by sewage were BOD (Biochemical Oxygen Demand), phosphorus, and total coliforms, which showed a significant increase with sewage discharge compared to the preserved area. The biochemical oxygen demand indicates an increase in microbiota with aerobic respiration expected to be present in the sewage, as confirmed by the increase in coliforms number.

Temperature tends to rise during the summer, a phenomenon exacerbated by climate changes caused by anthropogenic actions. Such a phenomenon directly impacts the proliferation capacity of microorganisms in aqueous environments. The table 1 showed also a strong effect of season, especially in the dry season. In the rainy season, the dilution effect reduced the concentration of Phosphorus and the microbial population.

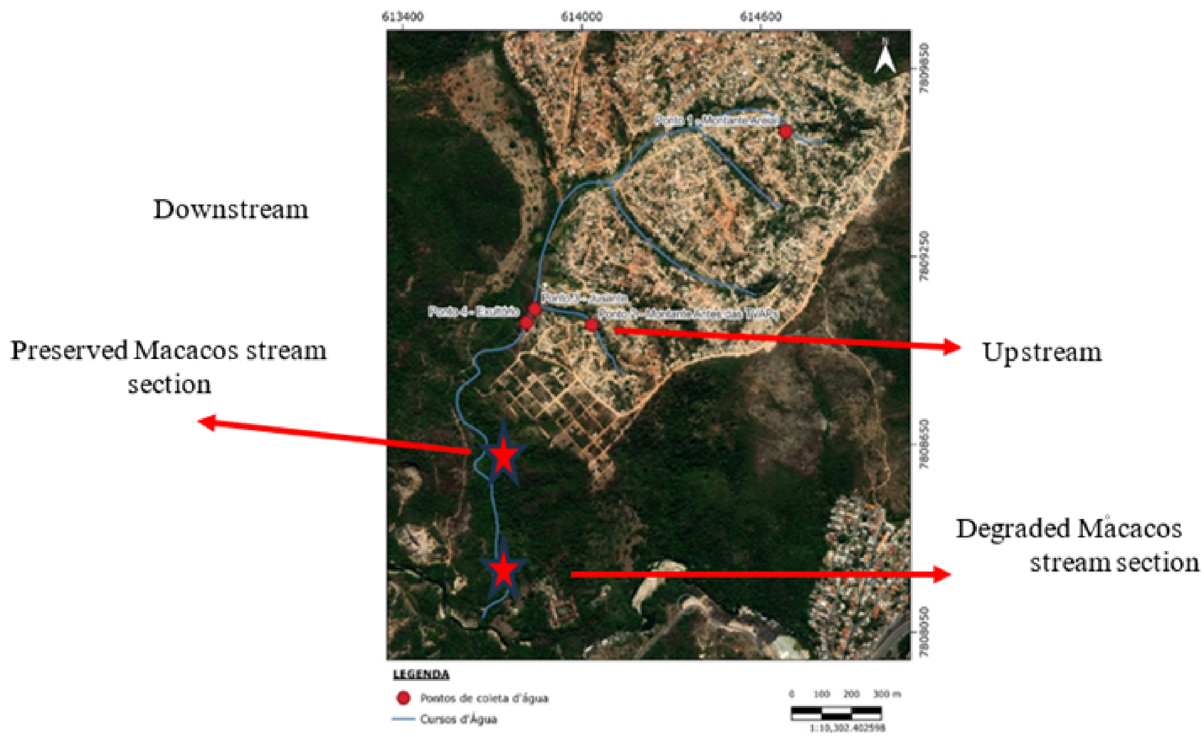

Fig. 4: Sampling areas on restored water course upstream and downstream

Table 1: Water quality analysis of preserved and impacted sections on Macacos stream

Local	Season	pH	Conductivity	BOD	Temperature	Phosphorus	Nitrate	Total coliform
			µS/cm	mg O2/L	ºC	mg /L	mg /L	MPN/**100mL**
Preserved Macacos Stream	Dry	7,98	246,5	4,36	16,35	350	180	$2,4\times10^{5}$
	Rainy	7,20	335,5	3,00	22,80	220	300	$2,4\times10^{5}$
P21 – Impacted Macacos stream (near Izidora River)	Dry	7,50	509,5	45,80	19,55	1865	20	$9,8\times10^{5}$
	Rainy	6,90	429,5	24,36	23,15	285	810	15×10^{5}

Table 2 shows the results of the analyses of samples collected upstream and downstream of the TEvap installation points. The greatest effect of the TEvaps was observed at Downstream 1, where a reduction in BOD, phosphorus, nitrate, and both thermotolerant and total coliforms was noted, especially compared to the upstream N1 point. These results suggest the effectiveness of the TEvaps after just one year after the installation.

Table 2: Water Quality analysis of N1 water course at upstream and downstream of TEvaps

	pH	Condutivity (µS/cm)	BOD (mg O2/L)	Temperature (º C).	Phosphorus	Nitrate	Thermotolerant coliforms (MPN)	Total Coliforms (MPN)
Upstream Areial	6,99	234	19	22,5	< 0,3 mg/L	20,7 mg/L	<1,8 /100 mL	17×10^5 /100mL
Upstream – N1 water course	6,00	237	42	22,5	1,41 mg/L	52,5 mg/L	$2,7 \times 10^3$/100 mL	$1,6 \times 10^5$ /100mL
Downstream - N1 water course - 1	6,38	309	6	22,4	< 0,3 mg/L	< 2,0 mg/L	< 1,8 /100mL	$0,11 \times 10^5$ /100mL
Downstream - N1/ Macacos stream - 2	7,82	294	58	22,7	< 0,3 mg/L	< 2,0 mg/L	< 1,8 /100mL	$1,6 \times 10^5$ /100mL

4- Discussion

The main indicators of fecal contamination from sewage were revealed by the increase in coliforms, BOD, as well as phosphorus and nitrate. The increase in phosphorus and nitrate is also related to the sewage discharge.

Phosphorus enrichment in rivers can degrade the plant community, both the higher plants and the algae by altering the competitive balance. This has consequences for the whole ecosystem due to the rupture of the trophic chain. [13]. On the other hand, high nitrate levels in the river indicates a persistent faecal contamination what improved the microbial growth and impact also plant and algae growth [14]. The TEvaps system was able to reduce BOD, total coliforms and phosphorus one year after its installation. Therefore, the results obtained indicate the effectiveness of the system, confirming results obtained by Paulo et al. (2019) along 4 years. However, in the vicinity of Macacos stream (samples N1/ 2), there was a worsening of the results suggesting new sewage input, probably from the Macacos stream.

5- Conclusion

1- Alternative and nature-based solutions for wastewater management should be prioritized in developing countries."
2- The preliminary results demonstrate the effectiveness of the TEvap system in reducing water fecal contamination.
3- The Evapotranspiration Tank (TEvap) is a highly effective and sustainable solution for blackwater management, particularly in regions where traditional sewage systems are not viable. One of the main advantages of the TEvap is its ability to operate without the need for extensive water resources or complex infrastructure. By utilizing natural processes, the system not only treats wastewater but also contributes to the local ecosystem through the introduction of vegetation.
4- The construction technology of TEvaps is simple and easily transferable to the settler community.
5- Another advantage of TEvaps is the low installation cost.
6- We consider the TEvap alternative to be recommended and promising as a replacement for traditional sewage treatment systems, offering a sustainable and environmentally friendly solution that can be adapted to a variety of climates and conditions.

Despite its benefits, the TEvap requires careful planning and design to ensure its effectiveness. The selection of appropriate plant species and soil types is crucial, as well as the design of the tank and distribution system to match local conditions. Additionally, the system requires regular monitoring and maintenance to ensure it continues to operate as intended.

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