water

MDPI

Article

Operation of a Zero-Discharge Evapotranspiration Tank for Blackwater Disposal in a Rural Quilombola Household, Brazil

Adivânia Cardoso da Silva [1], Adriana Duneya Diaz Carrillo [1,2] and Paulo Sérgio Scalize [3,*]

[1] CIAMB, Graduate Program in Environmental Sciences, Federal University of Goiás, Goiânia 74000-000, Brazil; adivaniaeng@gmail.com (A.C.d.S.); adrianadc@correo.unefm.edu.ve (A.D.D.C.)
[2] Environmental Science Program, Francisco de Miranda National Experimental University, Coro 4101, Venezuela
[3] CIAMB, PPGEAS, School of Civil and Environmental Engineering, Federal University of Goiás, Goiânia 74000-000, Brazil
* Correspondence: pscalize.ufg@gmail.com

Abstract

Decentralized sanitation in rural areas urgently requires accessible and nature-based solutions to achieve Sustainable Development Goal 6 (clean water and sanitation for all). However, monitoring studies of such ecotechnologies in disperse communities remain limited. This study evaluated the performance of an evapotranspiration tank (TEvap), designed with community participation, for the treatment of domestic sewage in a rural Quilombola household in the Brazilian Cerrado. The system (total area of 8.1 m^2, with about 1.0 m^2 per inhabitant) was monitored for 218 days, covering the rainy season and the plants' establishment phase. After 51 days, the TEvap reached operational equilibrium, maintaining a zero-discharge regime, and after 218 days, 92.3% of the total system inlet volumes (i.e., 37.47 in 40.58 m^3) were removed through evapotranspiration and uptake by cultivated plants (*Musa* spp.). Statistical analyses revealed correlations that were moderate to strong, and weak between the blackwater level and relative humidity (Pearson correlation coefficient, r = 0.75), temperature (r = −0.66), and per capita blackwater contribution (r = 0.28), highlighting the influence of climatic conditions on system efficiency. These results confirm the TEvap as a promising, low-maintenance, and climate-resilient technology for decentralized domestic sewage treatment in vulnerable rural communities, with the potential to support sanitation policy goals and promote public health.

Keywords: rural sanitation; nature-based solution; ecotechnologies; wastewater; low-cost technology; environmental sanitation

check for updates

Academic Editors: Enedir Ghisi, Célia dos Anjos Alves and António Manuel Abreu Freire Diogo

Received: 1 May 2025
Revised: 8 July 2025
Accepted: 11 July 2025
Published: 14 July 2025

Citation: da Silva, A.C.; Carrillo, A.D.D.; Scalize, P.S. Operation of a Zero-Discharge Evapotranspiration Tank for Blackwater Disposal in a Rural Quilombola Household, Brazil. *Water* **2025**, *17*, 2098. https://doi.org/10.3390/w17142098

1. Introduction

The search for effective and decentralized solutions for wastewater treatment has gained increasing relevance in a global context [1–4]. This trend reflects essential public policies to minimize water pollution and, consequently, reduce associated diseases [5,6]. In this context, the United Nations emphasizes the urgency for countries to advance in achieving the Sustainable Development Goals (SDGs) [7], particularly SDG 6 (clean water and sanitation), aligned with the 2030 Agenda [8].

Despite progress in sanitation coverage, disparities between urban and rural areas remain evident [9–11]. Isolated rural communities often face obstacles related to access, costs, and the technical feasibility of conventional sewage treatment systems [12,13].

Within Brazil's diverse sociocultural landscape, traditional peoples and communities—especially Quilombola communities—are disproportionately affected due to geographic isolation and historical exclusion [14,15]. Data from the Brazilian Institute of Geography and Statistics (IBGE) show that over 60% of the Quilombola population lives in rural areas [16], where access to sanitation is notably limited [17,18], and is especially lacking in adequate and low-cost treatment solutions [19].

In response to these challenges, low-cost and low-maintenance solutions such as zero-discharge evapotranspiration tanks (TEvap) have emerged as promising alternatives for decentralized wastewater treatment [20–22]. These systems have already been studied and implemented in Brazil [23], demonstrating their potential for nutrient absorption, safe effluent disposal, the promotion of plant growth [24–26], and fruit production [20–22,24,25]. The TEvap system operates by promoting the microbial degradation of organic matter and the gradual removal of water in vapor form, driven by high-demanding plants such as *Musa* spp. [27–30]. Most construction materials are low-cost and locally available, with the possibility of reusing waste materials such as tires and rubble [28,31,32].

However, despite the increasing adoption of this technology, few studies have examined the operation of TEvap systems at full-scale, especially under daily-use conditions in rural households. Important practical aspects—such as the sewage level within the system, water balance, and hydraulic response to climate variability—remain underexplored, which limits the ability to properly size and replicate these systems in vulnerable territories. Moreover, there is little knowledge about the performance of these systems when combined with social participation in their implementation and monitoring. This highlights a significant knowledge gap situated at the intersection of rural sanitation and environmental justice.

Thus, this study aims to evaluate the operation of a full-scale, zero-discharge TEvap system receiving blackwater from a household located in a rural Quilombola community in Central Brazil. Specifically, the study investigates the system's hydraulic behavior, identifying potential challenges and its adaptability to the local context. An interdisciplinary methodology was adopted, combining technical monitoring with participatory approaches involving local residents. Through this integrated analysis, the study seeks to contribute to the applied knowledge of decentralized sanitation technologies, particularly those aimed at dispersed rural populations.

2. Materials and Methods

2.1. Study Area

The Evapotranspiration Tank was constructed for serving a residence with 8 inhabitants in the Queixo Dantas community—Mimoso de Goiás, Goiás, Brazil (Figure 1). The municipality is located within the Cerrado Biome and has a climate defined as Aw, according to the Köppen–Geiger classification, which is a seasonal tropical climate with a dry winter (April to September) and a rainy summer (October to March). It has an average annual temperature of 27 °C and annual precipitation exceeding 750 mm, able to reach up to 1800 mm [33,34].

The Queixo Dantas Community is difficult to access and currently comprises 17 households, located 63.2 km from the urban center of the municipality of Mimoso de Goiás (80% unpaved and 20% paved road) and 367 km from Goiânia, the capital of the state of Goiás, Brazil. Regarding sanitation, 92.9% of the households use rudimentary septic tanks, and 7.1% discharge raw sewage directly onto the ground [35]. Concerning the water supply, 100% of its dwellings are supplied by a water supply system (WSS) that previously drew water collectively from the Queixo Dantas stream without any water treatment. This situation changed in 2022 when they began receiving water from a deep tubular well drilled exclusively for this community.

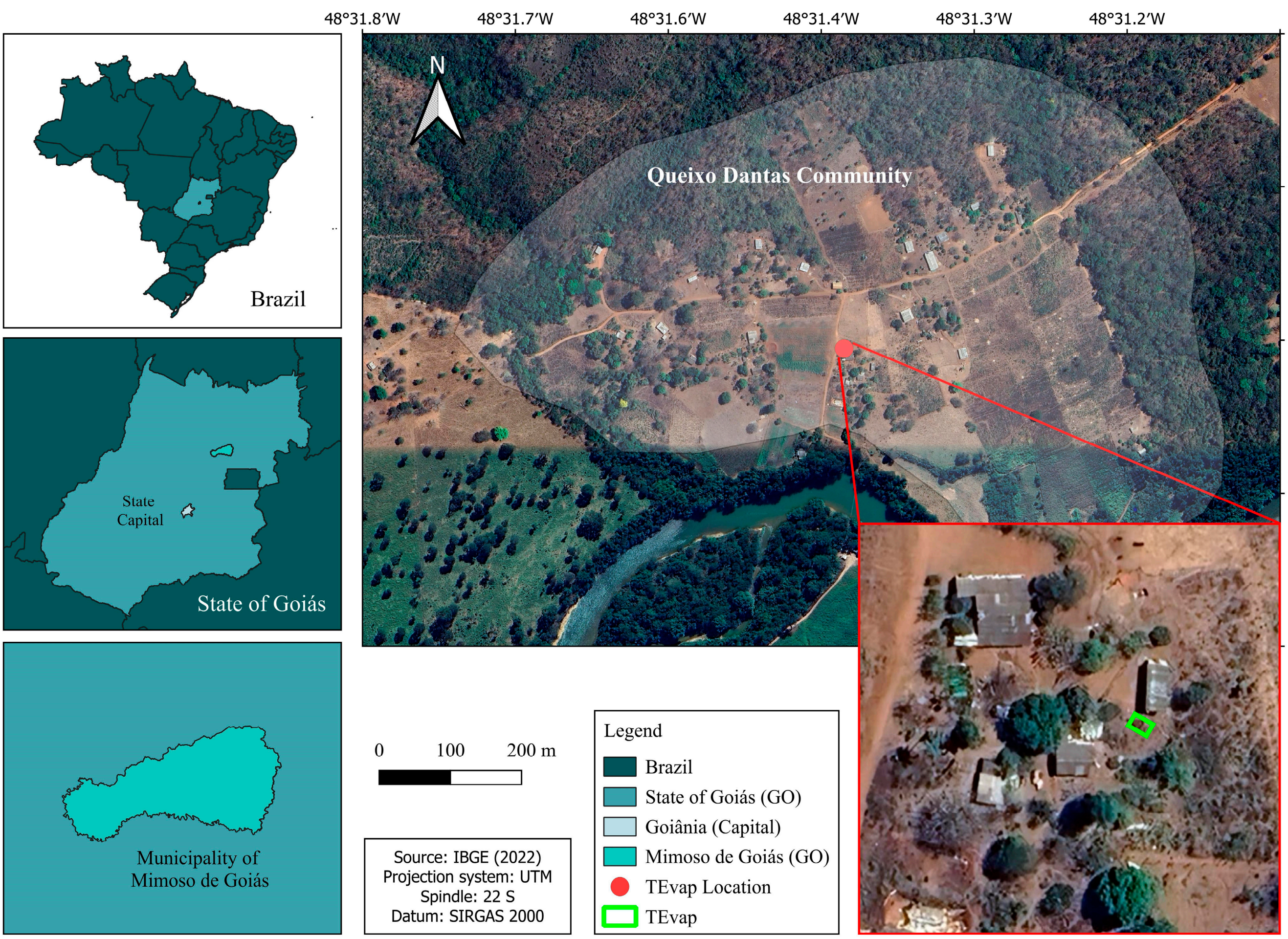
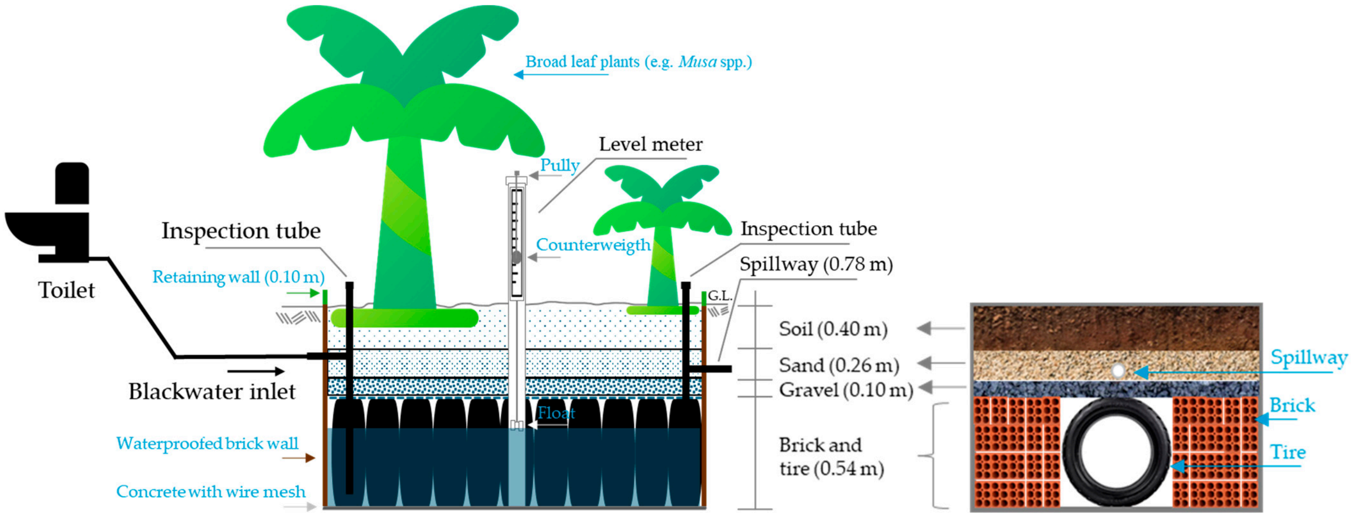


Figure 1. Geographic location of the evapotranspiration tank in the studied rural community, Goiás, Brazil.

2.2. *TEvap Characteristics*

The TEvap was constructed with the following dimensions: 5.40 m × 1.50 m × 1.30 m, presenting a surface area of 8.10 m^2, which is slightly more than 1.0 m^2/inhab. This value is between 0.6 [25] and 1.05 m^2/inhab. [36] for TEvaps designed as a nature-based solution for domestic sewage treatment in rural households in Brazil. The filling material was organized into four layers: 0.54 m of brick with tire chips, 0.10 m of gravel (No. 1), 0.26 m of sand, and 0.40 m of soil, being approximate values from the technical–scientific literature [29]. At the opposite end to the blackwater inlet, a spillway outlet was installed at a height of 0.78 m, corresponding to the maximum height of the blackwater inside the TEvap (Figure 2). However, as it is a zero-discharge solution, the spillway functions as an emergency device, activated only in case of overflow. To create the watertight compartment of the TEvap, masonry was used with the addition of a waterproofing additive (Vedacit®, São Paulo, Brazil), and finished with a bituminous coating (MastFrio Asfalto, Usina Anchieta®, São Paulo, Brazil). The bottom slab was constructed using reinforced concrete with a chain-link mesh (1.9 mm wire, Vonder®, Goiás, Brazil). The walls were built 0.10 m above ground level (G.L., Figure 2a), forming a containment curb to prevent flooding from rainwater.



(**a**) (**b**)

Figure 2. Illustration of TEvap (**a**), with details of the filling material layers (**b**).

In the soil layer, 12 banana seedlings (*Musa* spp.) of six varieties with different stages of development and size were planted: Nanica banana (*Musa acuminata* 'Dwarf Cavendish'), Nanicão (*M. acuminata*, Cavendish Group), Prata (*M.* x *paradisiaca*), Pacovan (*M.* x *paradisiaca*), marmelo (*M. acuminata* x *balbisiana*), and Maçã banana (*M. acuminata* x *M. balbisiana*, AAB Group, 'Silk'). These varieties are commonly cultivated in the community itself. In Brazil, these are the most consumed varieties [37], and were chosen for the TEvap due to the high water demand of these cultivars, favoring evapotranspiration [27]. Banana plants were purchased free of charge from the community. The total cost of materials was 701.7 USD (3465.5 BRL) [38], and may vary depending on local prices and the use of donated materials. An economic analysis, which was not performed in this study, is recommended to demonstrate the cost–benefit viability compared to other ecotechnologies.

2.3. Community Construction of the TEvap

The household chosen for the construction of the TEvap was selected collectively, and its construction was participatory, encouraging other families to also express interest in building this solution for blackwater disposal. Community participation was documented through on-site observation and open dialogues, using photographs, notes, and field reports [39,40]. It is noteworthy that the project implementation in the *Quilombola* community of Queixo Dantas and the collection of information from residents were approved by the Research Ethics Committee of the Federal University of Goiás (UFG), under opinion number 74841323.9.0000.5083, within the scope of the project "Situational analysis of *Quilombola* communities in Goiás and sharing of good practices in sanitation—TradSan". This initiative is the result of an interinstitutional collaboration between the Research Support Foundation (FUNAPE), the Federal University of Goiás (UFG), the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, and the Federal Public Ministry (MPF).

2.4. TEvap Monitoring

The TEvap was monitored from the beginning of its operation, on 19 September 2024, until 25 April 2025, totaling 218 days of operation, corresponding to the rainy season of the region. During this period, data on the variation of the blackwater levels inside the TEvap were collected to determine the volume of water, considering a void ratio in the brick and tire layer of 0.826, in the gravel layer of 0.464, and in the sand layer of 0.448, obtained from tests in an acrylic column to determine the void ratio of the ceramic brick, and jerrycans to determine the volume occupied by the tires [41]. For this, a mechanical level meter composed of a float and pulley was used (Figure 3a), being tested in the laboratory, with periodic field visits conducted for adjustments and to ensure proper functioning. The volume of blackwater that entered the TEvap was obtained indirectly by measuring the volume of water used in flushes. For this purpose, a volumetric water meter with a nominal flowrate (Qn) of 1.5 m^3/h, manufactured by the German brand Zenner (model RTK-S, Zenner International, Saarbrücken, Germany) was installed in the pipe that exclusively feeds the toilet (Figure 3b). The measurement of the water volume by the water meter, in turn, made it possible to estimate the per capita contribution of blackwater (Cp) based on the total volume of water consumed throughout the entire monitoring period. To ensure reading accuracy, the volumetric meter was subjected to performance verification tests by the Goiás Sanitation Company (Saneamento de Goiás S.A.—Saneago, Goiás, Brazil), which confirmed an error of less than 5%.

(**a**) (**b**)

Figure 3. Level measurement mechanism (**a**) and water meter installed before the toilet bowl to measure the volume of water used for flushing (**b**).

Furthermore, the volume of feces and urine was estimated, considering that a healthy adult excretes, on average, 128 g/day of feces and 1.5 L/day of urine, corresponding to approximately 9% of the water volume used in daily flushes [42]. The use of this value equally for the eight individuals in the household analyzed in this study may have slightly overestimated the Cp data, since not all of them are adults.

The volume of water used per flush was determined through on-site measurements taken during toilet flushing, based on readings recorded by the water meter. Ten consecutive readings were taken, from which the average volume per flush was obtained. This average value was then used to estimate the daily number of flushes, based on the estimated per capita blackwater contribution data during the TEvap monitoring period. The volume of water stored in the flush tank was also verified using a beaker and a 500 mL graduated cylinder.

2.5. Blackwater Sampling

To assess the quality of the blackwater inside the TEvap, samples were collected after 69 days of operation (27 November 2024) at two different points (QD1 and QD2, Figure 4a). For this purpose, a disposable manual sampler was used, made from a 250 mL plastic bottle cut in half and secured with braided cotton thread, which was inserted into the

150 mm inspection pipes with the aid of a 25 mm tubing. Two samples of 500 mL each were collected from the system's inlet (Figure 4b) and midpoint (Figure 4c). The samples were refrigerated for 24 h, and analyses were performed for the following parameters: pH (pH meter, Lucadema brand, Luca-210 model); electrical conductivity (conductivity meter, Bel Engineering brand, W12D model); color (photocolorimeter, PoliControl brand, AquaColor Cor model); turbidity (turbidimeter, Hach brand, 2100Q model); COD and BOD5, according to Standard Methods for the Examination of Water and Wastewater [43].

(**a**) (**b**) (**c**)

Figure 4. Collection of blackwater samples inside the TEvap at two different points (**a**): inlet (QD1) and midpoint of the system (QD2), using a manual sampler (**b**) made from a plastic bottle (**c**).

2.6. Water Balance in TEvap

In the first 20 days, it was necessary to supply water to ensure the elongation and rooting of the plants, since banana plants have minimal water reserves. Temporary water deficiency can cause serious damage to the plant, even leading to its death [44,45]. Thus, the irrigation of the plants for their adaptation within the TEvap at the beginning of operation was carried out using a sufficient volume of water to saturate the soil around the seedlings, averaging 8 to 10 L. In addition, the soil was partially covered with dry plant material, as recommended by the literature [44].

To complement the analysis of the water dynamics, climatological data (precipitation, temperature, and relative humidity) were extracted from the National Institute of Meteorology [46], from the Brazlândia-DF A042 automatic climatological station (Latitude: −15.5955, Longitude: −48.1301), which is located 64 km from the area of influence of the TEvap.

The volume of water resulting from evapotranspiration was calculated using Equation 1 of the water balance, considering the contribution recorded by the water meter and the estimates of fecal content, irrigation, and precipitation. For the calculation, the volume stored in the plants, the volume infiltrated into the walls of the TEvap, and possible leaks were disregarded. The equation was applied cumulatively for the total monitoring period (218 days), as well as for the progression period (51 days) and stabilization period (167 days), in relation to the blackwater level in the TEvap.

$$V_{Evap} = \left(V_{BWi} - V_{BWf}\right) + 1.09V_{BW} + V_P + V_I \tag{1}$$

where V_{Evap} = the evapotranspired volume in the Tevap (m^3); V_{BWf} = the final volume of blackwater within the Tevap (m^3); V_{Bwi} = the initial volume of blackwater within the Tevap (m^3); and V_{BW} = the volume of blackwater contribution in the analyzed period (m^3).

Obtained indirectly by the volume of water registered by the water meter in the toilet flushes, the constant 1.09 = the contribution of feces and urine in the analyzed period, with 9% of the V_{BW} [42]; V_P = the sum of rainfall precipitation in the analyzed period in terms of volume (m^3); and V_I = the volume of water used for irrigation during the period (m^3).

Pearson correlation analyses were conducted between the precipitation, temperature, relative humidity, blackwater level, and per capita contribution of blackwater over the entire monitoring period, adopting a 95% confidence level ($p < 0.05$) as the threshold for statistical significance. Correlations with p-values equal to or greater than 0.05 were not considered statistically significant.

3. Results

3.1. Community Involvement in the Construction of the Tevap

The banana seedlings were planted on 19 September 2024, in a participatory manner with the community. From this date, the monitoring of the zero-discharge Tevap, receiving blackwater, began. Visual analysis allowed the observation that until 15 October 2024 and 11 June 2024 (Figure 5a,b), the cultivars were still in the process of establishing themselves in the soil.

Figure 5. Evolution of the growth of *Musa* spp. cultivars in an Evapotranspiration Tank.

In the first 20 days of this period (19 September 2024 to 09 October 2024), irrigation was necessary to ensure the survival of the plants, since the rains only intensified from 10 October 2024 and the plants were not yet able to utilize the present blackwater in the TEvap. In the following months (Figure 5c–f), the adaptation of the banana plants was observed, evidenced by the elongation of the vegetative body and the increase in leaf area, which favored the evapotranspiration process. This development may have contributed to the stabilization of the blackwater level inside the TEvap.

3.2. TEvap Monitoring

3.2.1. Assessment of the Blackwater Inside the TEvap

Table 1 shows the values of the physicochemical and biological parameters of the blackwater inside the TEvap after 69 days of operation. An efficiency of 89.8% was observed in turbidity reduction, 74.6% in COD, and 81.4% in BOD5 in samples collected at the system's inlet (QD1) and midpoint (QD2).

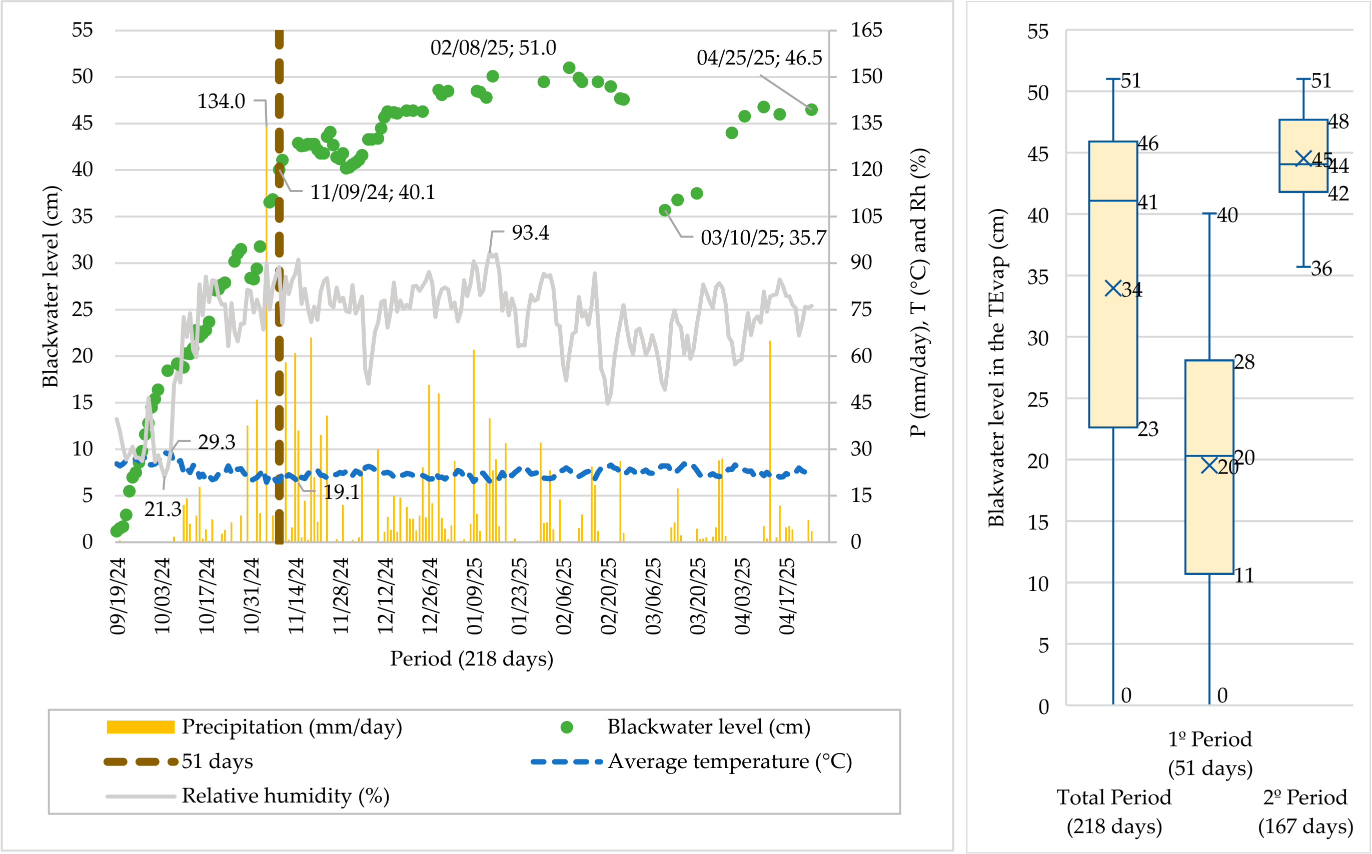
Table 1. Physicochemical and biological parameters of domestic blackwater inside the TEvap.

Sample	pH	EC (mS/m)	Color (Uc)	Tur. (NTU)	COD (mg.L^{-1})	BOD$_5$ (mg.L^{-1})
QD1	7.7	2.8	312.0	529.0	1755.0	451.0
QD2	7.5	2.9	256.0	54.2	446.5	84.0
	Efficiency (%)		17.9	89.8	74.6	81.4

Note: QD1 = system inlet (point 1); QD2 = system midpoint (point 2); EC = Electrical Conductivity; Tur = Turbidity; COD = Chemical Oxygen Demand; BOD5 = Biochemical Oxygen Demand.

3.2.2. Blackwater Levels Inside the TEvap and Water Balance

Regarding the monitoring of the TEvap over 218 days (Figure 6), with the system operating under air temperatures ranging from 19.13 to 29.01 °C (median = 22.4 °C; average = 22.6 °C; coefficient of variation = 0.1), precipitation fluctuating between 0.0 and 134.0 mm/day (median = 0.6 mm/day; average = 7.5 mm/day; coefficient of variation = 2.1) and relative humidity between 21.3 and 93.4% (median = 74.6%; average = 70.3%; coefficient of variation = 0.2), it is observed that the system exhibited a progressive filling behavior until 11 September 2024 (Period 1, lasting 51 days), reaching a level of 40.1 cm. From that date onwards, an equilibrium was established between blackwater inflow and the evapotranspiration process (Period 2, 11 September 2024 to 25 April 2025, 167 days), with level variations from 35.7 cm to 51.0 cm. At the end of the monitoring, the blackwater level was at 46.5 cm.



(**a**) (**b**)

Figure 6. Blackwater level in the TEvap, air temperature (T), rainfall (P), and relative humidity (Rh) during the monitoring period (**a**) and variation of the blackwater level inside the TEvap in the different analyzed periods (**b**).

All the water used for flushing, which generated the blackwater that entered the TEvap, was recorded by the volumetric water meter, totaling 24.07 m^3 (V_{BW}). Considering the volume of feces and urine (V_{BW}), estimated at 9% of the consumed water volume [42], 2.16 m^3, the total volume of blackwater generated was 26.24 m^3. In addition to this volume, there was the contribution of water from irrigation and precipitation. For irrigation, approximately 8 L of water per plant were used in the first 20 days (beginning of the rainy season), with ten irrigations of 96 L each (8 L × 12 seedlings), totaling 0.96 m^3 (V_I). The contribution from precipitation was 13.39 m^3 (V_P). Thus, over the 218 days of monitoring, the total volume that entered the system was 40.58 m^3.

Considering the final volume of blackwater stored in the TEvap on 04/25/25 (level = 46.5 cm), occupying only the tire and brick layer (below the gravel layer), the volume of blackwater in the TEvap corresponds to 3.11 m^3 ($V_{BWf} = 8.1\ m^2 \times 0.465\ m \times 0.826$), being 0.826 the void index [41]. Based on these data and applying Equation (1), it is estimated that 37.47 m^3 (V_{Evap}) were consumed in the system through evapotranspiration processes, absorption by plants, wetting of the filling materials (walls, bricks, gravel, and sand), and evaporation from the soil, corresponding to 92.3% of the total water input (Table 2).

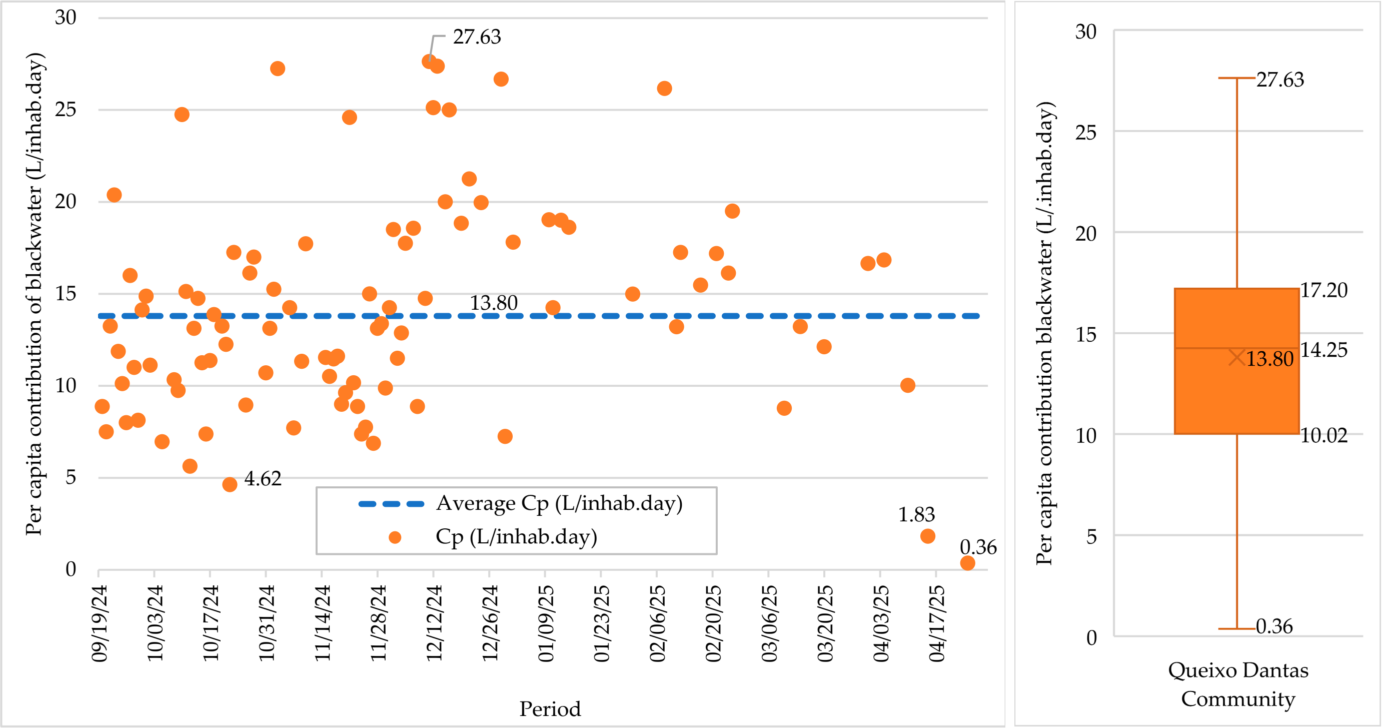
Table 2. Periods of fluctuation in blackwater level and evapotranspiration in the TEvap, monitored for 218 days.

Period	Total Days	Blackwater Level at TEvap (cm)		Blackwater Volume in TEvap (m^3)		VBW (m^3)	VFU (m^3) (0.09 × VBW)	VI (m^3)	VP (m^3)	VEvap (m^3)	VEvap (%)
		Initial	Final	V_{BWi}	V_{BWf}						
P1	51	0.0	40.1	0.00	2.68	4.93	0.44	0.96	2.78	6.43	70.6
P2	167	40.1	46.5	2.68	3.11	19.14	1.72	0.00	10.60	31.04	98.6
TP	218	0.0	46.5	0.00	3.11	24.07	2.16	0.96	13.39	37.47	92.3

Note: Period 1, from 09/19/24 to 11/09/24 = P1; Period 2, from 11/09/24 to 04/25/25 = P2; Total period, from 09/19/24 to 04/25/25 = TP; V_{BWi} = initial volume of blackwater within the TEvap; V_{BWf} = final volume of blackwater within the TEvap; V_{BW} = volume of blackwater, a function of the water volume recorded by the water meter; V_{FU} = estimated volume of feces and urine, being 9% of V_{BW}; V_I = volume of water used for irrigation during the period (m^3); V_P = sum of rainfall precipitation in the analyzed period in terms of volume (m^3); V_{Evap} = volume of evapotranspired water.

Table 2 presents a synthesis of the analysis of the entire monitoring period (218 days). It is observed that, in the initial filling period (Period 1—51 days), 6.43 m^3 were consumed by evapotranspiration, which represents 70.6% of the water input in this interval. In the equilibrium period (Period 2—167 days), the evapotranspired volume was 31.04 m^3, corresponding to 98.6% of the total received by the system during this operational interval. This equilibrium time depends on factors such as the climate, type and number of plants, irrigation, and input volume, and should not be generalized without proper adjustment to these variables.

Complementarily, it was verified that the daily volume recorded by the water meter, referring exclusively to toilet flushes, was 110.41 L/day. Considering a residence with eight inhabitants, this value corresponds to an average of 13.8 L/inhab.day (Figure 7). During the progression period (P1), considering that the water meter recorded a volume of 4.93 m^3 (Table 2), the average Cp resulted in 12.07 L/inhab.day, while in the stabilization period (P2), it was 14.33 L/inhab.day. It is also observed that the highest per capita contribution was 27.6 L/inhab.day, while the lowest was 0.36 L/inhab.day (Figure 7a,b). Approximately 50% of the per capita contribution is between 10.0 and 17.2 L/inhab.day, with 50% being less than or equal to 13.8 L/inhab.day.



(**a**) (**b**)

Figure 7. Daily per capita contribution of blackwater that the TEvap received during the monitored period (**a**) and variation of the per capita contribution throughout the total period (**b**). Note: the additional contribution of feces and urine was not considered.

Regarding the measurements of the volume used per flush, it was identified that the toilet in the analyzed household has a demand of 7.0 L/flush on average. Considering the average Cp value throughout the entire period, without considering the volume of feces and urine (13.8 L/inhab.day), it is possible to infer that each resident performs, on average, two flushes daily (13.80 ÷ 7.0). When estimating the Cp, considering an addition of 9%, referring to the load of feces and urine [42], a long-term average value of per capita blackwater contribution of 15.04 L/inhab.day was obtained. For the specific periods, the estimated values were 13.16 L/inhab.day in P1 and 15.62 L/inhab.day in P2.

The statistical analysis of the variables in Figures 6 and 7 suggested a Pearson correlation coefficient (r) ranging from weak to moderate ($-0.60 < r < 0.60$) and strong ($|r| > 0.6$) [47]. The correlation between Cp and temperature ($r = 0.09$) was weak, indicating no reliable association. In contrast, significant correlations were found between the Cp and relative humidity ($r = 0.14$), and between the Cp and blackwater level ($r = 0.28$), although the strengths of these associations were weak. Strong correlations were observed between the blackwater level and relative humidity ($r = 0.75$), and between the blackwater level and temperature ($r = -0.66$), suggesting that local climatic conditions may influence the behavior of the TEvap system. However, more robust statistical analyses could better identify these relationships, considering a longer time series and multiple units.

4. Discussion

The collaboration of families from the Queixo Dantas community was fundamental for the construction of the TEvap, demonstrating ownership of knowledge, empowerment, and commitment to the sustainable development of their surroundings. Similar behaviors have been reported in Brazil regarding community participation in the construction of social technologies in rural communities [48]. Community participation is fundamental in the transformation and diffusion of social technologies for sanitation in rural areas in a decentralized manner [49].

The construction of the TEvap represented an opportunity for the community to acquire technical knowledge on nature-based solutions for domestic wastewater treatment. Residents demonstrated satisfaction with the benefits received, as evidenced in statements such as:

> "*I am very happy to receive the TEvap. Now I know that banana plants help to treat the sewage that we generate every day. Thank you!*"

> "*Wow, now the yard is so much better without the stench of sewage around the house.*"

In the Queixo Dantas community, 92.9% of households dispose of blackwater in rudimentary septic tanks, while 7.1% discharge it directly into the soil [35]. Faced with this scenario, the adoption of social technologies such as the TEvap proves to be a viable alternative for all households, addressing the lack of sanitation and promoting the improvement of the local population's quality of life. Simple construction technologies with low cost and reduced maintenance requirements, such as the TEvap, could replace the combination of septic tanks and infiltration systems [29], and with lower implementation costs [25]. Maintenance refers to occasional pruning, the control of cultivar growth, and the removal of excess sludge after a certain period, for example, every 4 to 5 years [32]. Furthermore, "the ideas of decentralization and participation empower and strengthen the citizenship of the served population, which further drives the universalization of sanitation" [50], especially in the current context of climate change, which demands increasing efforts for the mitigation of environmental impacts.

Local climatic conditions such as air temperature and rainfall can directly affect the performance, efficiency, and long-term sustainability of evapotranspiration systems used for the treatment of domestic sewage. Low temperatures can negatively influence evapotranspiration, since plant transpiration has a direct relationship with increasing temperatures [51].

The ideal temperature for the development of banana plants is around 28.0 °C [52], slightly above the average recorded at the TEvap installation site. It is worth noting that the minimum (19.1 °C) and maximum (29.0 °C) values observed during monitoring were within the tolerance range for the crop, whose extreme limits are 15.0 °C and 35.0 °C [52].

Regarding precipitation, the average rainfall volume was 7.5 mm/day (CV = 2.1). On 05/11/24, it rained 134 mm (Supplementary Data, Table S1); considering that this entire volume infiltrated proportionally to the TEvap area, the volume would increase by 1.1 m^3 (134 mm $\div$ 1000 $\times$ 8.1 m^2) and, consequently, the system level. In rainy periods, the performance of evapotranspiration beds can be compromised, as a water load exceeding the system's capacity may result in a higher risk of saturation, increasing the chance of overflow. For example, willow beds designed for the zero-discharge treatment of domestic sewage can be directly influenced by precipitation, leading to malfunction [53].

Climatic variables such as temperature, precipitation, solar radiation, and wind speed, among others, exert a direct influence on the water balance [54]. Associated with these variables, the surface area of the TEvap is a fundamental parameter in the design of evapotranspiration tanks. In the present study, an area of about 1.0 m^2 per inhabitant was adopted, demonstrating suitability for system stabilization. This parameter was based on the lower values found in the literature of 0.6 m^2/inhabitant [25] and 1.25 m^2/inhabitant [36], considering the low blackwater generation per capita typical of rural communities [55]. Although the technical literature suggests larger areas of 1.5–2.0 m^2/inhabitant [21,23], the efficiency observed in the TEvap confirms that reduced sizing can be viable when aligned with specific local conditions. Adopting the higher values suggested by the literature would result in an overestimation of the unit, which could imply additional costs in construction and system operation. The sizing of the required area of an evapotranspiration tank for sewage treatment in a specific locality can be determined through a representative water balance of the region.

In evaluating the performance of the TEvap during the monitoring period, it was possible to infer that the system operated under a zero-discharge regime, as the blackwater level did not reach the overflow height (78.0 cm). If overflow had occurred, the surrounding soil would have received an organic load of $\leq$84.0 mg$\cdot$L^{-1} BOD5 and 446.5 mg$\cdot$L^{-1} COD—lower than the typical load of raw domestic sewage. For comparison, untreated wastewater (e.g., from rudimentary septic tanks) usually contains up to 400.0 mg$\cdot$L^{-1} BOD5 and 1016.0 mg$\cdot$L^{-1} COD [56], highlighting the potential of the TEvap to mitigate possible environmental contamination.

Furthermore, in none of the analyzed periods did the rainfall exceed evapotranspiration (Table 2). In locations where precipitation exceeds evapotranspiration, the proper functioning of systems based on this principle may be compromised [57]. Thus, considering that the TEvap apparently ensured the containment of blackwater—that is, it prevented leaks or infiltrations through the walls and bottom slab—and there was no overflow, it is understood that the system presented good performance [21]. The non-infiltration of sewage through the walls and slab can be inferred from the variation in the blackwater level that occurred during the monitoring period, which rose and fell several times, reaching a maximum height of 51.0 cm and a minimum of 35.7 cm only once (Figure 6). Leakage and/or overflow of sewage in evapotranspiration systems designed for zero-discharge operation has been reported in the literature [28,36,57], which may pose a risk to the surrounding environmental matrices. The drop in blackwater levels to 35.7 cm on 10/03/25 (Figure 6a) may be due to an increase in the local temperature and a decrease in rainfall during this period, favoring evapotranspiration.

In this study, overall, of the total volume of blackwater that entered the TEvap (40.58 m^3), 92.3% was removed by evapotranspiration, exceeding the 80% reported in the literature [20]. During the progression period of the blackwater level (51 days, $R^2 = 0.955$), it was observed that 70.6% (6.43 m^3) of the 9.11 m^3 received was evapotranspired. In the first 20 days, the system received 1.74 m^3, of which 27.5% (0.48 m^3) was removed, which may be related to the initial wetting of the bed materials and surface evaporation. The process of pore saturation in the filling materials tends to occur gradually [25]. During this interval, sanitary discharges were the only source of water input, as there was no precipitation and all the water used in irrigation was absorbed by the plants during their adaptation phase. In the system equilibrium period (167 days), 98.6% (31.04 m^3) of the total volume received was removed, predominantly by evapotranspiration [58], a behavior that corroborates theoretical data for banana plants (*Musa* spp.) in arid ecosystems (Caatinga), where plants with 60 days of growth consume 16.6 L/day, increasing to 34.86 L/day in advanced stages (210 days) [59]. In our study, carried out in the Cerrado (tropical savanna), a similar pattern was observed: in the progression phase (57 days), evapotranspiration (70.6% of the volume removed) reflected the root and leaf establishment of the seedlings (Figure 5a,b), while in P2 (167 days), the increase in efficiency (98.6%) coincided with intensive vegetative growth (Figure 5e,f) and greater water demand. This convergence between empirical and theoretical data, even in different biomes, reinforces the direct influence of the phenological stage on the evapotranspiration capacity of the TEvap and its effectiveness as a treatment system in different climatic contexts.

It was observed that evapotranspiration, rainfall, and Cp were key variables in the monitoring of the TEvap and in the identification of its zero-discharge operation. The water level in the TEvap (Figure 6) is regulated not only by the stage of plant growth, but also by the climatic conditions and blackwater inflow (Figure 7). This study highlighted this through a strong Pearson correlation between the blackwater level and relative humidity (r = 0.75) and per capita contribution (r = 0.28), emphasizing the importance of sizing adaptation to local conditions and water use behavior. It is recommended that these variables faithfully reflect the conditions of the area where the technology is intended to be implemented, in order to avoid undersizing or oversizing in the design. For example, the long-term Cp estimated in this study (13.8 L/inhab.day—Figure 7), if replaced by a lower value such as 9.9 L/inhab.day [36], could result in undersizing of the TEvap. On the other hand, the adoption of a high value, such as 33.0 L/inhab.day [60], could overestimate the system, with the risk of overflow and compromised performance. The value found in this study of 13.8 L/inhab.day differs by only 1.7 L/inhab.day from the Cp of 12.10 L/inhab.day [55], referring to a rural community during 49 days of monitoring, also performing on-site measurements. Cp values can vary depending on water use behavior. Thus, factors such as holidays, visits, family gatherings, or trips to the city can also significantly impact the volume of water used daily in households [55]. Outliers in Cp values were identified throughout the monitoring period. One example is the peak of 27.6 L/inhab.day (Figure 7a), which may be related to the constant presence of residents at home, considering that 63% (five out of eight members) are of school age. Conversely, values significantly lower than the long-term average, such as the Cp of 4.6 L/inhab.day (Figure 7a), which is equivalent to less than a single daily flush per inhabitant, may reflect the temporary absence of residents. It is important to highlight that the lowest recorded Cp values may also indicate a reality of lower water consumption in rural areas compared to urban areas. In Brazil, water consumption is 8.8% in urban areas and only 2.4% in rural zones [61].

The demand of the toilet bowl also directly influences the values of the Cp. Conventional toilet bowls generally consume between 6 and 12 L per flush [62]. Considering a contribution of 13.8 L/inhab.day and an average consumption of 7.0 L per flush, it is estimated that each inhabitant flushes the toilet approximately 1.97 times a day. This value is within the range reported in the literature, varying from 1.27 [57] to 4.0 flushes/inhab.day [63].

The higher the daily frequency of flushing, especially in toilets with greater water consumption per flush, the greater the volume of blackwater generated. This implies the need for treatment systems with larger storage capacity and, consequently, proportionally larger treatment areas per inhabitant to maintain process efficiency.

Thus, this study contributes to the understanding of the TEvap as a nature-based, zero-discharge solution for the treatment of blackwater in rural areas. The application of the solution with community participation can generate ownership of the technology and ensure its long-term sustainability, which can be explored in future projects.

5. Recommendation

Long-term monitoring, exceeding 12 months, is recommended as it is essential to evaluate the system's cost-effectiveness in treating domestic blackwater compared to other solutions (wetlands, septic tanks, etc.) under different climatic and seasonal conditions (rainy and dry season). It is suggested that other TEvaps with a diversity of plants (papaya, taro, among others) and/or other filling materials (rubble, gravel, among others) be monitored, as a replacement for tires, bricks, crushed stone, and sand, for example. Additionally, to ensure system resilience under extreme climatic conditions—such as excessive rainfall or prolonged droughts—it is recommended to include a safety margin in the design.

Evapotranspiration can be measured by phenological stage (e.g., sprouting, vegetative growth, flowering), and soil moisture sensors or evapotranspiration models should be used to quantify the water demand at each growth stage of the cultivar. For this purpose, microclimatic factors (such as relative humidity and solar radiation) should be considered and statistically correlated with system efficiency.

When installing the TEvap in other regions, its efficiency may be equal to or even greater than the values observed in this study, provided that the evapotranspiration rate does not exceed the local precipitation. To ensure optimal performance, the selected plants should have high water demand and be adapted to the specific climate of each region. In temperate or cold regions, willows (*Salix* spp.) could efficiently replace banana plants (*Musa* spp.), which are well adapted to tropical and subtropical climates.

The goal of the TEvap is not to cultivate plants for harvest, and the cultivated species are not necessarily intended for consumption. However, this type of technology can not only enhance the landscape aesthetically but also potentially produce edible fruits. In such cases, microbiological analyses of the fruits are essential to ensure safe consumption. In this regard, it is recommended that long-term evaluations be conducted on the composition of the effluent and the soil within the TEvap, as well as their effects on the cultivated plants and the generated sludge. This will ensure that the system is not only functional but also safe for the environment and public health. Moreover, during the construction, community participation is recommended to ensure ownership and empowerment.

In the implementation of alternative blackwater treatment systems in rural areas, it is suggested to consider the socioeconomic and cultural context, family composition, and variations in the per capita contribution of blackwater, in order to optimize the design and operation of the solution. When variability in blackwater flow is not adequately absorbed by natural mechanisms, the installation of retention chambers or modular systems is recommended.

In the present study, the water volume associated with infiltration, leaks, or variability in plant absorption was not considered in the water balance calculation. Future studies could employ appropriate instrumentation to monitor these potential losses in order to reduce errors or the under/overestimation of evapotranspiration.

6. Conclusions

This study on the implementation and initial monitoring of an evapotranspiration tank (TEvap) in a rural Quilombola household provided valuable insights into its performance under local specificities. The system operated with zero discharge over a 7-month period, effectively treating blackwater by reducing turbidity, COD, and BOD_5, even with a design area of 1.0 m^2/inhabitant—smaller than commonly reported in the literature. Climatic variables such as the relative humidity, temperature, and precipitation were shown to influence the blackwater level in the system, which stabilized after 51 days of operation despite rainfall inputs. An initial adaptation phase was observed for the cultivated plants (*Musa* spp.), suggesting that aligning system startup with the rainy season or providing initial irrigation may enhance performance. Community participation played a key role in the system's success and long-term sustainability. Overall, the TEvap demonstrated its potential as an efficient, low-cost, nature-based solution for decentralized blackwater treatment in rural areas. By aligning with local environmental and social conditions, this ecological sanitation approach can contribute to health promotion, improved quality of life, and the advancement of national rural sanitation policy objectives—particularly in the context of achieving Sustainable Development Goal 6 (clean water and sanitation for all).

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/w17142098/s1, Table S1: Level and volume of blackwater in the Evapotranspiration Tank (TEvap) and data on per capita contribution of blackwater (Cp), air temperature, precipitation and relative humidity of the monitoring period for the analyzed household in the rural community of Queixo Dantas in Goiás, Brazil.

Author Contributions: Conceptualization, A.C.d.S., A.D.D.C. and P.S.S.; methodology, A.C.d.S., A.D.D.C. and P.S.S.; software, A.C.d.S. and P.S.S.; validation, A.C.d.S., P.S.S. and A.D.D.C.; formal analysis, A.C.d.S., A.D.D.C. and P.S.S.; investigation, A.C.d.S., P.S.S. and A.D.D.C.; resources, A.C.d.S. and P.S.S.; data curation, A.C.d.S. and P.S.S.; writing—original draft preparation, A.C.d.S. and P.S.S.; writing—review and editing, A.C.d.S., P.S.S. and A.D.D.C.; visualization, A.C.d.S.; supervision, P.S.S.; project administration, P.S.S.; funding acquisition, P.S.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research was supported by the Federal Public Ministry in partnership with the German Cooperation Agency GIZ (Deutsche Gesellschaft für Internationale Zusammenarbeit) and the Research Support Foundation (Funape) of the Federal University of Goiás, through contract no. 83433360.

Data Availability Statement: The rainfall and air temperature data used are freely accessible and can be consulted at the link: https://mapas.inmet.gov.br/ (accessed on 18 March 2025).

Acknowledgments: The authors express gratitude to the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) for the scholarship granted to the first author of this work; the PAEC Brazil Scholarship Program Organization of American States—Coimbra Group (OAS-GCUB); the Coordination for the Improvement of Higher Education Personnel (CAPES) and the Goiás Research Support Foundation (FUNAPE) for the scholarship granted to the second author; and the Environmental Sciences Program of the Francisco de Miranda National Experimental University (UNEFM), Venezuela, for the study permit granted to the second author.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. López-Vinent, N.; Santacruz, A.P.; Sales-Alba, A.; Cruz-Alcalde, A.; Redondo, I.D.; Pérez, S.; Sans, C. Nature-Based Solution as an Efficient Wastewater Pretreatment to Enhance Micropollutants Abatement by Solar Photo-Fenton at Natural pH. *J. Environ. Chem. Eng.* **2023**, *11*, 110834. [CrossRef]
2. Tian, A.; Chang, Y.; Yao, D.; Zhou, Y.; Xu, Q.; Tang, Q. A Modular Coupling System for EfficientTreatment of Rural Domestic Wastewater. *Pol. J. Environ. Stud.* **2023**, *32*, 1371–1381. [CrossRef] [PubMed]
3. Ma, L.; Li, Z.; Liu, G.; Liu, W. Low-Level Cadmium Alleviates the Disturbance of Doxycycline on Nitrogen Removal and N_2O Emissions in Ditch Wetlands by Altering Microbial Community and Enzymatic Activity. *J. Clean. Prod.* **2023**, *387*, 135807. [CrossRef]
4. Gomes, É.O.; Bomfim, T.O.D.; Santos, R.L.; Cohim, E.H.B.; Melo, S.L.D.; Machado, A.R.; Carvalho, D.E.B.D.; Silva, P.V.S.R. Avaliação do impacto ambiental de dois sistemas de tratamento de esgoto, reator uasb e lagoa anaeróbia: Uma análise no ciclo de vida (ACV). *Rev. Contemp.* **2024**, *4*, e3981. [CrossRef]
5. World Health Organization. *Guidelines on Sanitation and Health*; World Health Organization: Geneva, Switzerland, 2018.
6. Cruz, N.; Mierzwa, J.C. Saúde Pública e Inovações Tecnológicas Para Abastecimento Público. *Saude Soc.* **2020**, *29*, e180824. [CrossRef]
7. United Nations. *Transforming Our World: The 2030 Agenda for Sustainable Development, 2015*. Available online: https://sustainabledevelopment.un.org/post2015/transformingourworld (accessed on 5 March 2025).
8. United Nations. ODS 6, 2020. Available online: https://unstats.un.org/sdgs/report/2020/goal-06/ (accessed on 16 March 2025).
9. Pinilla-Rodríguez, D.E.; Torres-Sánchez, Y.A. Gasto Público Social, El Acceso al Agua Potable y El Saneamiento de Las Poblaciones Rurales En América Latina. *RPD* **2019**, *50*, 196. [CrossRef]
10. Queiroz, V.C.; Carvalho, R.C.D.; Heller, L. New Approaches to Monitor Inequalities in Access to Water and Sanitation: The SDGs in Latin America and the Caribbean. *Water* **2020**, *12*, 931. [CrossRef]
11. SNIS. Panorama do Saneamento Básico no Brasil 2021, 2021. Available online: https://www.gov.br/cidades/pt-br/acesso-a-informacao/acoes-e-programas/saneamento/snis/produtos-do-snis/PANORAMA_DO_SANEAMENTO_BASICO_NO_BRASIL_SNIS_2021compactado.pdf (accessed on 16 June 2025).
12. Mejía, A.; Castillo, O.; Vera, R. *Agua Potable y Saneamiento en la Nueva Ruralidad de América Latina*; Banco de Desarrollo de Americo Latina-CAF: Bogotá, Colombia, 2016.
13. Maciel, J.K.V.S.; Feitosa, P.H.C.; De Araújo, M.M.C.; Rocha, E.G.; Batista, G.D.S.; Fonseca, R.F.D.N.; Feitosa, F.C.; Leite, L.L. Avaliação dos Sistemas de Tratamento de Esgoto em Municípios de Pequeno Porte na Paraíba. *OLEL* **2023**, *21*, 17344–17362. [CrossRef]

14. Brasil. Decreto N° 8.750, 2016. Available online: https://www.planalto.gov.br/ccivil_03/_ato2015-2018/2016/decreto/d8750.htm (accessed on 10 March 2025).
15. Brasil. Decreto Nº 4.887, 2003. Available online: https://www.planalto.gov.br/ccivil_03/decreto/2003/d4887.htm (accessed on 5 March 2025).
16. IBGE. Censo Demográfico, 2022. Available online: https://cidades.ibge.gov.br/brasil/panorama (accessed on 11 June 2025).
17. Vale, G.B.D.; Ruggeri Junior, H.C.; Scalize, P.S. Service and Precariousness of Sanitary Sewage in Rural Communities in the State of Goiás, Brazil. *Eng. Sanit. Ambient.* **2022**, *27*, 1067–1075. [CrossRef]
18. Marcon, A.M.; Wesz Junior, V.J. The "New" Legal Framework and the Universalization of Basic Sanitation in Rural Areas. *Rev. Bras. Estud. Urbanos Reg.* **2024**, *26*, e202441pt. [CrossRef]
19. Jegatheesan, V.; Pachova, N.; Velasco, P.; Mowjood, M.I.M.; Weragoda, S.K.; Makehelwala, M.; Trang, N.T.D.; Dang, B.; Tran, C.; Vo, T.; et al. Co-development of an Integrated Assessment Framework to Evaluate the Effectiveness and Impact of Selected Nature-based Water Treatment Technologies in Sri Lanka, The Philippines, and Vietnam. *Environ. Qual. Mgmt* **2023**, *32*, 335–365. [CrossRef]
20. Galbiati, A.F. Tratamento Domiciliar de Águas Negras Através de Tanque de Evapotranspiração, 2009. Available online: https://repositorio.ufms.br/bitstream/123456789/1163/1/Adriana%20Farina%20Galbiati.pdf (accessed on 10 March 2025).
21. Figueiredo, I.C.S.; Barbosa, A.C.; Miyazaki, C.K.; Schneider, J.; Coasaca, R.L.; Magalhães, T.M.; Tonetti, A.L. Bacia de Evapotranspiração (BET): Uma Forma Segura e Ecológica de Tratar o Esgoto de Vaso Sanitário. *R. DAE* **2019**, *67*, 115–127. [CrossRef]
22. Ferreira, M.M.; Fiore, F.A.; Saron, A.; Da Silva, G.H.R. Systematic Review of the Last 20 Years of Research on Decentralized Domestic Wastewater Treatment in Brazil: State of the Art and Potentials. *Water Sci. Technol.* **2021**, *84*, 3469–3488. [CrossRef] [PubMed]
23. Pamplona, S.; Venturi, M. Esgoto à flor da terra. In *Esgoto à Flor da Terra—Sistema de Evapotranspiração é Solução Simples, Acessível e Sustentável*; Fazenda Experimental da Ressacada: Florianópolis, Brazil, 2004; pp. 18–19.
24. Paulo, P.L.; Galbiati, A.F.; Magalhães Filho, F.J.C. *CataloSan: Catálogo de Soluções Sustentáveis de Saneamento: Gestão de Efluentes Domésticos*, 1st ed.; Fundação Nacional de Saúde: Brasília, Brazil, 2018.
25. Coelho, C.F.; Reinhardt, H.; Araújo, J.C.D. Fossa Verde Como Componente de Saneamento Rural Para a Região Semiárida do Brasil. *Eng. Sanit. Ambient.* **2018**, *23*, 801–810. [CrossRef]
26. Figueiredo, I.C.S.; Dos Santos, B.S.C.; Tonetti, A.L. *Tratamento de Esgoto Na Zona Rural: Fossa Verde e Círculo de Bananeiras*, 1st ed.; FECFAU: Campinas, Brazil, 2018.
27. Reis, M.C.G.; Borges, A.C.; Ferreira, F.S.; Cunha, F.F.D.; Da Silva, R.R. A Preliminary Experimental Study Simulating Evapotranspiration Process in TEvap Tanks Cultivated with Different Forages. *Environ. Technol.* **2024**, *45*, 3129–3140. [CrossRef] [PubMed]
28. Paulo, P.L.; Galbiati, A.F.; Magalhães Filho, F.J.C.; Bernardes, F.S.; Carvalho, G.A.; Boncz, M.Á. Evapotranspiration Tank for the Treatment, Disposal and Resource Recovery of Blackwater. *Resour. Conserv. Recycl.* **2019**, *147*, 61–66. [CrossRef]
29. Paulo, P.L.; Azevedo, C.; Begosso, L.; Galbiati, A.F.; Boncz, M.A. Natural Systems Treating Greywater and Blackwater On-Site: Integrating Treatment, Reuse and Landscaping. *Ecol. Eng.* **2013**, *50*, 95–100. [CrossRef]
30. Magalhães Filho, F.J.C.; De Queiroz, A.A.F.S.L.; Machado, B.S.; Paulo, P.L. Sustainable Sanitation Management Tool for Decision Making in Isolated Areas in Brazil. *IJERPH* **2019**, *16*, 1118. [CrossRef] [PubMed]
31. Machado, G.C.X.M.P.; Roale, C.; Sobrinho, F.X.; Ruprecht, T.; Oliveira, F.J.d.R. *Caminhos e Cuidados Com as Águas: Faça Você Mesmo seu Sistema de Saneamento Ecológico*, 23rd ed.; Fundação Oswaldo Cruz: Rio de Janeiro, Brazil, 2019.
32. Reis, M.C.G.; Borges, A.C.; Cunha, F.F.D.; Silva, R.R.D. Evapotranspiration Beds as a Zero-Discharge Nature-Based Solution for Wastewater Disposal: A Review. *Ecol. Eng.* **2023**, *189*, 106896. [CrossRef]
33. Alvares, C.A.; Stape, J.L.; Sentelhas, P.C.; De Moraes Gonçalves, J.L.; Sparovek, G. Köppen's Climate Classification Map for Brazil. *Metz* **2013**, *22*, 711–728. [CrossRef] [PubMed]
34. Costa, H.C.; Marcuzzo, F.; Ferreira, O.M.; Andrade, L.R. Espacialização e Sazonalidade Da Precipitação Pluviométrica Do Estado de Goiás e Distrito Federal (Seasonality and Spatial Distribution of Rainfall in the State of Goiás and Federal District). *Rev. Bras. Geog. Fis.* **2012**, *5*, 87–100. [CrossRef]
35. Scalize, P.S.; Rocha, B.S.; Lopes, D.P.; Lopes, H.T.L.; Ruggeri Junior, H.C.; Roque e Lima, J.d.O.; Mendonça, J.S.A.; Hora, E.R.; Santo Filho, K.d.E.; Moreira, L.P.; et al. *Diagnóstico Técnico Participativo da Comunidade de Mimoso (Queixo Dantas), Mimoso de Goiás, Goiás, 2019*, 1st ed.; Cegraf UFG: Goiânia, Brazil, 2021.
36. Pires, F.J. Construção Participativa de Sistemas de Tratamento de Esgoto Doméstico no Assentamento Rural Olga Benário—MG, 2012. Available online: https://locus.ufv.br/items/eeba88f8-5c90-4fd1-98c6-47a0ae20f085 (accessed on 14 January 2025).
37. Embrapa. *A Cultura da Banana*, 3rd ed.; Embrapa: Brasília, Brazil, 2006.
38. BCB. Cotações, 2025. Available online: https://www.bcb.gov.br/ (accessed on 12 June 2025).
39. Arias, F. *El Proyecto de Investigación. Introducción a la Metodología Científica*, 6th ed.; Central University of Venezuela: Caracas, Venezuela, 2012.

40. Balestrini, M.A. *Como se Elabora el Proyecto de Investigación*, 7th ed.; Consultores Asociados: Caracas, Venezuela, 2005.
41. Sillva, A.C.; Carrillo, A.D.D.; Scalize, V.B.; Lamarre, K.; Ruggeri Junior, H.C.; Albuquerque, A.; Scalize, P.S. Variação Do Volume Útil Em Bacia de Evapotranspiração Para Tratamento de Esgoto Faecal, 2024. Available online: https://iceubi2024.pt/wp-content/uploads/2025/01/LIVRO-DE-ATAS_FINAL-07_01_2025-1.pdf (accessed on 12 June 2025).
42. Rose, C.; Parker, A.; Jefferson, B.; Cartmell, E. The Characterization of Feces and Urine: A Review of the Literature to Inform Advanced Treatment Technology. *Crit. Rev. Environ. Sci. Technol.* **2015**, *45*, 1827–1879. [CrossRef] [PubMed]
43. APHA. *Standard Methods for the Examination of Water and Wastewater*; APHA: Washington, DC, USA, 2023.
44. Embrapa. *O Cultivo da Bananeira*, 1st ed.; Embrapa: Brasília, Brazil, 2004.
45. Costa, S.C.; Soares, A.A.; Sediyama, G.C.; Viana, T.V.D.A.; Moreira, F.V.D.O. Variação de parâmetros físicos e químicos de frutos em bananeira 'pacovan' submetida a diferentes lâminas de irrigação e doses de potássio na Chapada do Apodi—Limoeiro do Norte-CE. *IRRIGA* **2011**, *16*, 82. [CrossRef]
46. INMET. Mapa Interativo de Monitoramento Meteorológico. Available online: https://mapas.inmet.gov.br/ (accessed on 18 March 2025).
47. Callegari-Jacques, S.M. *Bioestatística: Princípios e Aplicações*; Amazon Technologies, Inc.: Seattle, WA, USA, 2008.
48. Oliveira, C.G.D.; Chaves, S.R.M.; Carvalho, L.R.D.; Morais, T.D.F.; Lourenço, A.M.G. Disseminação de Tecnologias Sociais Para Tratamento de Esgoto Doméstico Na Zona Rural de Princesa Isabel—PB e Região. *RPSE* **2020**, *8*, 99. [CrossRef]
49. Dos Santos, J.L.; Dos Santos, C.A.P. Educação ambiental como instrumento do saneamento em comunidade quilombola, Entre Rios—BA. *Rev. Geogr. Acad.* **2022**, *15*, 121–134.
50. Machado, G.C.X.M.P.; Haguenauer, C.J.; Ruprecht, T.; Sobrinho, F.X.; Gallo, E. Ecological Sanitation: A Territorialized Agenda for Strengthening Traditional Communities Facing Climate Change. In *Climate Change Adaptation in Latin America*; Leal Filho, W., Esteves De Freitas, L., Eds.; Climate Change Management; Springer International Publishing: Cham, Switzerland, 2018; pp. 103–129. [CrossRef]
51. Allen, R.G.; Pereira, L.S.; Raes, D.; Smith, M. *Crop Evapotranspiration Guidelines for Computing Crop Water Requirements*; FAO: Rome, Italy, 1998.
52. Embrapa. *Sistema de Produção da Bananeira Irrigada*; Embrapa: Brasília, Brazil, 2009.
53. Curneen, S.; Gill, L. Upflow Evapotranspiration System for the Treatment of On-Site Wastewater Effluent. *Water* **2015**, *7*, 2037–2059. [CrossRef]
54. Frank, P.E.W.L. Engineering Parameters in the Design of Evapotranspiration Beds, 2000. Available online: https://www.wwdmag.com/wastewater-treatment/article/10917092/engineering-parameters-in-the-design-of-evapotranspiration-beds (accessed on 14 April 2025).
55. Da Silva, A.C.; Scalize, P.S.; Albuquerque, A. Assessment of per Capita Contribution to Fecal Sewage in Rural Residences of Quilombola Communities. *Water* **2025**, *17*, 1350. [CrossRef]
56. Metcalf&Eddy. *Wastewater Engineering: Treatment and Resource Recovery*, 5th ed.; Amazon Technologies, Inc.: Seattle, WA, USA, 2014.
57. Balley, P.; Dakers, A.J. Non-Discharging Evapotranspiration Bed System for Wastewater Disposal at Lincoln. *Environ. Monit. Assess.* **1996**, *43*, 65–72. [CrossRef] [PubMed]
58. Beebe, D.A.; Castle, J.W.; Molz, F.J.; Rodgers, J.H. Effects of Evapotranspiration on Treatment Performance in Constructed Wetlands: Experimental Studies and Modeling. *Ecol. Eng.* **2014**, *71*, 394–400. [CrossRef]
59. Embrapa. *Irrigação da Bananeira*; Embrapa: Brasília, Brazil, 2012.
60. Santos Junior, E.L.d. Tecnologia Alternativa para Tratamento Seletivo dos Resíduos Provenientes da Bacia Sanitária em Comunidades Rurais, 2019. Available online: https://tede.unioeste.br/handle/tede/4203 (accessed on 15 April 2025).
61. ANA. Conjetura de Recursos Hídricos no Brasil, 2017. Available online: https://www.snirh.gov.br/portal/snirh/centrais-de-conteudos/conjuntura-dos-recursos-hidricos/conj2017_rel-1.pdf (accessed on 12 June 2025).
62. Kujawa-Roeleveld, K.; Zeeman, G. Anaerobic Treatment in Decentralised and Source-Separation-Based Sanitation Concepts. *Rev. Environ. Sci. Biotechnol.* **2006**, *5*, 115–139. [CrossRef]
63. Costa, T.H.S.; Mota, F.S.B. Análise Quantitativa de Águas Cinza Em Um Condomínio Residencial. *Eng. Sanit. Ambient.* **2022**, *27*, 413–421. [CrossRef]