Edição especial – VI Winotec

ISSN 1808-8546 (ONLINE) 1808-3765 (CD-ROM)

DESEMPENHO DO SISTEMA BIOÁGUA IMPLANTADO NO COLÉGIO INDÍGENA ESTADUAL DOM JOSÉ BRANDÃO DE CASTRO*

LAÍSSY MESSIAS DOS SANTOS [1]; RAIMUNDO RODRIGUES GOMES FILHO [2]; LUCIANA COÊLHO MENDONÇA [3] E GREGÓRIO GUIRADO FACCIOLI [4]

[1]Programa de Pós-Graduação em Recursos Hídricos, Universidade Federal de Sergipe, Av. Marcelo Deda Chagas, s/n, Bairro Rosa Elze, CEP 49107-230, São Cristóvão, SE, Brasil, laissymessias@gmail.com, https://orcid.org/0000-0003-0456-5415
[2]Departamento de Engenharia Agrícola, Universidade Federal de Sergipe, Av. Marcelo Deda Chagas, s/n, Bairro Rosa Elze, CEP 49107-230, São Cristóvão, SE, Brasil, rrgomesfilho@hotmail.com, https://orcid.org/0000-0001-5242-7581
[3]Departamento de Engenharia Civil, Universidade Federal de Sergipe, Av. Marcelo Deda Chagas, s/n, Bairro Rosa Elze, CEP 49107-230, São Cristóvão, SE, Brasil, lumendon@academico.ufs.br, https://orcid.org/0000-0001-6979-8135
[4]Departamento de Engenharia Agrícola, Universidade Federal de Sergipe, Av. Marcelo Deda Chagas, s/n, Bairro Rosa Elze, CEP 49107-230, São Cristóvão, SE, Brasil, gregorioufs@gmail.com, https://orcid.org/0000-0003-2666-3606
**Artigo oriundo da Dissertação de Mestrado de Laíssy Messias dos Santos: "Desempenho do tratamento de água cinza em um Sistema Bioágua". UFS,2024.*

1 RESUMO

Em alguns períodos do ano, em regiões áridas e semiáridas, a demanda por água torna-se maior que os recursos hídricos disponíveis localmente. Para reduzir impactos sociais e ambientais decorrentes dessa realidade, regularizar o reúso de água pode ser uma alternativa sustentável para tornar melhor a rotina de uma comunidade. Assim, objetivou-se nesta pesquisa avaliar o desempenho do tratamento de água cinza em um Sistema Bioágua (SBA), onde foram determinadas as características da água cinza bruta e tratada através dos parâmetros físicos, químicos e microbiológicos, para analisar a qualidade da água cinza tratada para atender aos critérios de uso na irrigação. O SBA apresentou bom desempenho e valores satisfatórios de CE, STD, Nitrato, Nitrito, Óleos e graxas, OD, pH e RAS para uso na irrigação, segundo diretrizes pertinentes, mas indicou valores discordantes de Turbidez, Amônia e Fosfato.

Palavras-chave: escassez hídrica, tratamento de efluentes, tecnologia social.

SANTOS, L. M; GOMES FILHO, R. R.; MENDONÇA, L. C.; FACCIOLI, G. G. PERFORMANCE OF THE BIOÁGUA SYSTEM IMPLEMENTED AT THE DOM JOSÉ BRANDÃO DE CASTRO STATE INDIGENOUS COLLEGE

Recebido em 03/12/2024 e aprovado para publicação em 12/12/2024
DOI: http://dx.doi.org/10.15809/irriga.2024v29p220-235

2 ABSTRACT

At certain times of the year, in arid and semiarid regions, the demand for water becomes greater than that for locally available water resources. To reduce the social and environmental impacts of this situation, regulating water reuse can be a sustainable alternative to improve the routine of a community in these regions. The aim of this research was to evaluate the performance of gray water treatment in a biowater system (BWS), where the characteristics of the raw gray water and treated gray water were determined via physical, chemical and microbiological parameters, and to assess the quality of the treated gray water to meet the criteria for use in irrigation. The BWS showed good performance and satisfactory values for EC, TDS, nitrate, nitrite, oil and grease, DO, pH and SAR for use in irrigation, according to the relevant guidelines, but indicated discordant values for turbidity, ammonia and phosphate.

Keywords: water scarcity, effluent treatment, social technology.

3 INTRODUCTION

Water is an essential resource for providing basic services to the population, such as energy supply and generation, but it is also an indispensable element for the aquaculture, agriculture and fishing sectors, in addition to providing tourism and leisure activities. However, in some regions, the available water does not meet the demand of the local community, such as in arid and semiarid regions. By 2050, approximately half of the world's urban population (1.693 to 2.373 billion people) is expected to live in regions with water scarcity, including 19 megacities (He *et al*., 2021). Given this reality, alternative sources, such as the use of rainwater and the reuse of treated wastewater as a subsidy, can be used to reduce the social and environmental impacts resulting from water scarcity in these regions.

The practice of reusing treated wastewater contributes to more sustainable management of water resources by increasing the amount of necessary water resources, reducing the discharge of effluents into water bodies, protecting aquatic ecosystems and reducing the amount of pollutants released into the soil and aquatic environments (Mendonça; Mendonça, 2017). The possibilities for reusing treated effluents are diverse but preferable for nonpotable purposes, emphasizing that each use requires a different level of quality. As a strategy to contribute to the spread of water reuse in the semiarid region of Brazil, it is necessary to develop efficient social technologies (STs) with low implementation, operation and maintenance costs.

STs emerged in Brazil in 2000 and are reusable techniques and/or methodologies developed in interaction with the community that represent effective solutions for social transformation (Dagnino, 2010). Some STs are aimed at the treatment and reuse of gray water as a tactic to address water deficit during irrigation and save water supplies for activities that require better quality water, such as the Banana Circle, Filter Garden, Vermifilter and Biowater Systems. These TSs have the common function of improving the quality of gray water for safe use in the intended activity, but the definition of the technology to be used depends on the quality of the effluent, which can be determined from the analysis of the physical, chemical and microbiological characteristics.

In view of the above, this work aims to evaluate the performance of the treatment and reuse of gray water in a biowater system through analyses of physical, chemical and microbiological parameters to evaluate the quality of the treated gray water according to the criteria required for the application of reused water in irrigation.

4 CONTEXTUALIZATION

4.1 Gray water reuse

Research and public policies on water reuse have expanded, especially in relation to gray water reuse, due to the water deficit in some regions (Pinto *et al.*, 2021). In Brazil, even with unproven feasibility, the number of buildings with gray water reuse systems is gradually growing in favor of sustainability.

Eriksson *et al*. (2002) define gray water as effluent generated by the use of washing machines or dishwashers, kitchen sinks, bathtubs, showers and washbasins, but from another perspective, Nunes (2014), when defining gray water, disregards the effluent originating from the use of kitchen sinks and dishwashers owing to high concentrations of oils and fats. However, the aforementioned authors consider gray water to differ from raw sewage because it does not contribute to the effluent generated by the use of toilets. According to Borges (2003), gray water that comes from bathtubs, showers and washbasins contains fats, soaps, oils and other pollutants; gray water originating from washing machines or laundries has high chemical concentrations of sodium, phosphate, nitrogen, boron and surfactants; and gray water originating from dishwashers or kitchen sinks presents greater physical contamination due to the presence of food particles, fats and oils.

According to Barbosa (2019), as it is an effluent with a lower content of organic matter and pathogenic microorganisms than does the effluent derived from the use of toilets, gray water can be reused for nonpotable purposes, such as irrigation, toilet flushing, firefighting, and car washing.

Oteng-Peprah, Acheampong and deVries (2018) consider that, for sustainable water management, the practice of gray water reuse becomes an instrument for reducing the demand for drinking water, but the risks associated with reuse must be considered.

4.2 Biowater systems implemented in the Brazilian semiarid region

The bioágua System has been a ST that has been disseminated since 2009, when it was implemented in family homes in São Geraldo in Olho D'Água do Borges/RN through the Dom Hélder Câmara Project (PDHC), naming it the Family Bioágua System (SBF), but in 2013, the implementation was strengthened with the installation of 200 SBFs in Sertão do Apodi/RN through the Petrobras Socioenvironmental Project (Santiago *et al*., 2015).

In 2015, the Bem Viver Institute (IBV) implemented 13 SBFs in communities in the Sertão dos Crateús and Sertão dos Inhamuns regions in the state of Ceará (IBV, 2018). Additionally, in that year, the Volunteers Association for International Service Brazil (AVSI Brazil) developed the Food Security Project for the Semiarid Region of Pernambuco, which built 131 SBFs in municipalities in the Pernambuco hinterland (Gouveia, 2015).

The following year, in 2016, the IBV implemented 35 SBFs in Ceará communities in the municipalities of Independência, Ipaporanga and Monsenhor Tabosa (IBV, 2018) and AVSI BRASIL through the Sustainable Pankaiwka Project: Biowater, Agroecology and Nutrition for a Healthy Village, which built two SBFs in the Pankaiwka Indigenous Village located in Tacaratu, PE (Gouveia, 2017).

In 2017, a model SBF was installed at the Dom Fragoso Agricultural Family School in Independência/CE, and five SBFs were installed at Aldeia Fidélis in Quiterianópolis/CE (IBV, 2018).

Between 2016 and 2019, 22 SBFs were initially implemented, and 32 SBFs were later implemented by AVSI Brazil in Jucati/PE through the Jucati Sustentável 1 and Jucati Sustentável 2 projects, respectively (Gouveia, 2018).

With the Enel Shares Infrastructure Project – Family Biowater, AVSI Brazil, in 2018, benefited families from the municipalities of Cafarnaum/BA and Morro do Chapéu/BA with the implementation of 60 SBFs (Gouveia, 2019).

In the microregion of Sertão de Crateús/CE, in the municipalities of Monsenhor Tabosa, Nova Russa and Tamboril, the Esplar Research and Advisory Center implemented 29 SBFs through the Education for Freedom Project (EPL) in 2019 (ESPLAR, 2019).

Between 2021 and 2023, AVSI Brazil implemented 29 SBFs in Campo Formoso/BA and Juazeiro/BA through the Sustainable Semi-Arid Project and 20 SBFs in the rural area of Mata de São João/BA through the Semear & Colher project (AVSI, 2022).

In Sergipe, in 2019, two SBFs were implemented in the municipalities of Poço Redondo and Feira Nova by the Water Reuse Project for the Promotion of Productive Backyards in the Semiarid Region of Northeast Brazil (Santos, 2020). In addition, in 2024, the Pangea Institute implemented the biowater system presented in this research at the Dom José Brandão de Castro State Indigenous School located in the municipality of Porto da Folha.

The systems implemented in semiarid communities, in addition to promoting water reuse and contributing to food security, enable the growth of family income due to the opportunity to sell surplus food produced in productive backyards.

4.3 National legislation and standards for water reuse

Although water reuse occurs in some regions of Brazil, the lack of specific legislation with well-defined guidelines makes it difficult to spread the practice, but there are national laws and standards that discuss the subject, such as the following:

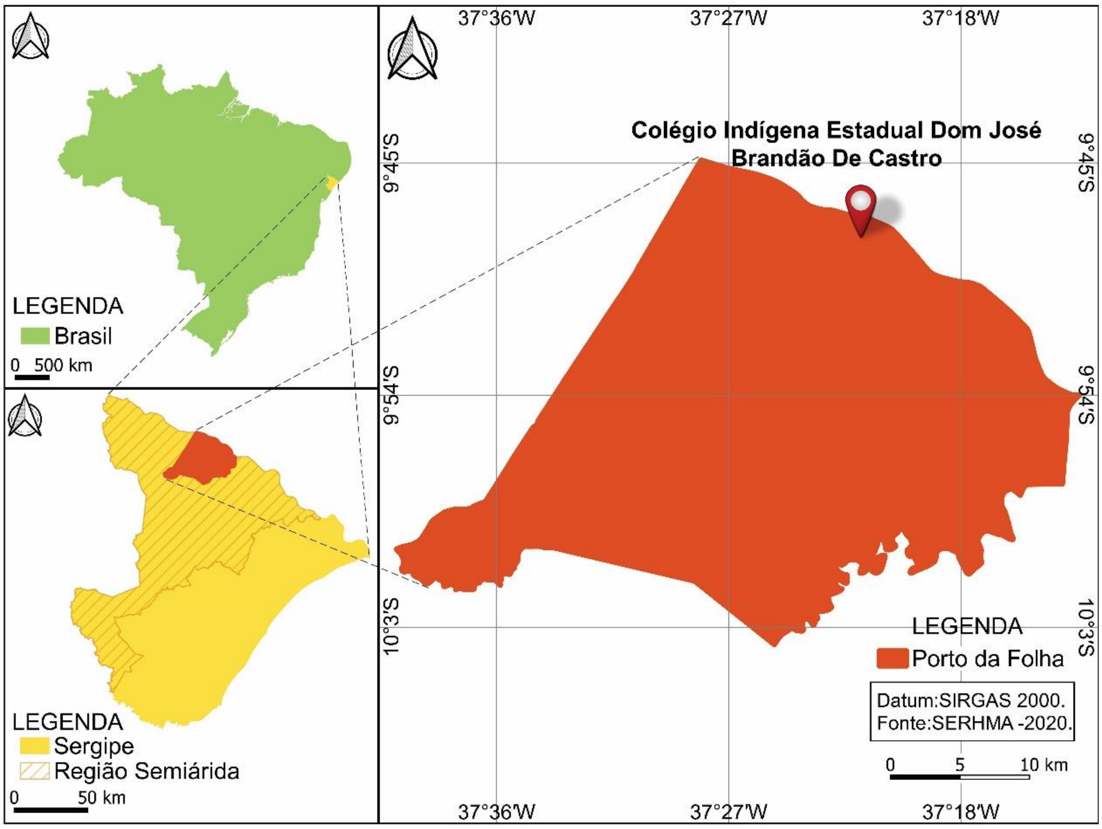
- Resolution No. 357/2005 of the National Environmental Council (CONAMA): classifies and establishes the quality levels of fresh, brackish and saline waters, and for each class, it is defined in which activity the water can be used appropriately (Brazil, 2005a);
- Resolution No. 121/2010 of the National Water Resources Council (CNRH): establishes guidelines and criteria for the practice of direct nonpotable reuse of water in agriculture and forestry and considers that water reuse reduces costs associated with pollution, contributing to the protection of the environment and public health (Brazil, 2010);
- NBR 16783/19 from ABNT (use of alternative sources of nonpotable water in buildings): considers irrigation, washing floors and vehicles, flushing toilets, landscaping and pastures as nonpotable uses and defines quality standards for reused water for safe reuse (ABNT, 2019);
- Federal Law No. 14.546/2023: decrees that the Union encourages the nonpotable reuse of gray water after treatment in new buildings and in landscaping, agricultural, forestry and industrial activities (Brazil, 2023).

5 MATERIALS AND METHODS

5. 1 Study Area

The research was carried out at the Dom José Brandão de Castro State Indigenous School (CIEDJBC) in the indigenous territory of Ilha de São Pedro, located in the municipality of Porto da Folha, in the microregion of the São Francisco backlands in the state of Sergipe, 153 km from the capital Aracaju/SE (Figure 1). The municipality is characterized by a caatinga biome and has geographic coordinates of 9°55'10" South, 37°16'29" West and an altitude of 38 m above sea level. The total area of the school is equivalent to 4,922.64 m², where the main building, the multisports court, the Bioágua System (SBA) and the cistern are located.

Figure 1. Location of CIEDJBC



Source: SERHMA (2020).
Author: Eng. José Carlos Benício do N. Filho (2023)

Given the water shortage in the community, the SBA was built to encourage the use of socioenvironmental technologies for capturing, storing and using water and to allow students to use the water treatment system as a learning space.

5.2 Biowater System

The SBA performs treatment by means of a physical and biological impediment mechanism for the waste contained in the gray water coming from the school kitchen sink. The system consists of a grease trap with a useful volume of $0.175m^3$, a biological filter with a useful volume of $4.83m^3$, a reuse tank with a useful volume of 4.83m^3, a nursery with a thousand seedlings of 25 different native tree species from the Caatinga, a worm farm and a pump house (Figure 2). The biological filter has a downward flow and is composed of five layers: earthworm humus (10 cm), wood shavings (50 cm), washed sand (10 cm), gravel (10 cm) and Pebbles (20 cm). Part of the organic matter present in gray water is biodegraded by the population of California red earthworms (*Eisenia fetida*), which are included in the first layer.

Figure 2. Components of the Biowater System

Legend: A- Grease trap; B- Biological filter; C- Electric pump house; D- Reuse tank; E- Worm farm; F- Nursery; G- Biowater system
Source: Authors (2024)

As a form of reuse, as defined by the World Health Organization (1973), the SBA in this study is classified as internal recycling since the system promotes internal reuse in school facilities and aims to save water and control pollution. In addition, in relation to the reuse modality as defined in Resolution No. 54 of the National Environmental Council (CONAMA) (Brazil, 2005b), the system is classified for environmental purposes, since the reused water is used to implement environmental recovery projects, because later, when the seedlings reach the ideal structure for planting, they will be used for the reforestation project of the indigenous territory, recovering water sources, caatinga areas and riparian forest.

5.3 Characterization of gray water and analysis for use in irrigation

To evaluate the efficiency of SBA through the chemical, physical and microbiological characteristics of gray water, the raw gray water and treated gray water were sampled and analyzed every seven days, resulting in six samples in the experimental period of 36 days.

The sample analyses were carried out by the integrated laboratories of the Sergipe Sanitation Company (DESO), located in the city of Aracaju/SE, according to methodologies described by the Standard Methods for the Examination of Water and Wastewater (APHA, 2017), with the exception of the pH and temperature parameters, which were analyzed on site, using a pocket pH meter model AK95 from AKSO.

The parameters analyzed were as follows:

- Physical: electrical conductivity (EC), apparent color, total dissolved solids (TDS), temperature (T) and turbidity;
- Chemicals: Ammonia (NH_3), calcium (Ca), free residual chlorine, phosphate (PO_4), magnesium (Mg), nitrate (NO_{3}^{-}), nitrite (NO_{2}^{-}), oils and greases, dissolved oxygen (DO), hydrogen potential (pH) and sodium (Na);
- Microbiological: Total coliforms and *Escherichia coli* (*E. coli*).

To evaluate the use of treated gray water from legal aspects for agricultural reuse, a survey of national and international documents and legislation was carried out to address water quality for use in irrigation (Table 1). Since treated gray water is used for the irrigation of tree crops, it is worth noting that when consulting CONAMA resolution no. 357 (Brazil, 2005a) as a reference for analyzing the parameters, the conditions and standards required for class 3 freshwater were considered.

Table 1. Analytical methods and maximum allowable values

PARAMETER	VMP	REFERENCE
PHYSICAL PARAMETERS		
Turbidity (uT)	≤ 100 uT	CONAMA 357/2005 (Brazil, 2005a)
CHEMICAL PARAMETERS		
NH_3 (mg /L)	≤ 5 mg/L	FAO (Ayers ; Westcot,1985)
PO_4 (mg/L)	≤ 2 mg/L	FAO (Ayers ; Westcot,1985)
NO_3^- (mg/L)	≤ 5 mg/L	*Guidelines for water reuse 2012* (USEPA, 2012)
	≤ 10 mg/L	FAO (Ayers ; Westcot,1985)
NO_2^- (mg/L)	≤ 1.0 mg/L	CONAMA 357/2005 (Brazil, 2005a)
Oils and greases (mg/L)	Virtually Absent	CONAMA 357/2005 (Brazil, 2005a)
DO (mg/L)	≥ 4 mg/L	CONAMA 357/2005 (Brazil, 2005a)
pH	6.5 – 8.4	FAO (Ayers ; Westcot,1985)
MICROBIOLOGICAL PARAMETERS		
E.coli (CFU/100 ml)	≤ 10^4 E.coli/100 ml	Treatment and use of sewage (PROSAB, 2006)
	≤ 4,000 NMP/100 ml	CONAMA 357/2005 (Brazil , 2005a)
	10^5 E.coli/100 ml – 10^6 E.coli/100 ml	Guidelines for the safe use of wastewater, excreta and graywater (World Health Organization , 2006)

Source: Authors (2024)

The EC and TDS analyses were used to assess the risk of soil salinization, and the sodium adsorption ratio (SAR) and EC were used to assess the risk of reducing the water infiltration rate in the soil, according to the FAO recommendations for interpreting the quality of water for irrigation (Table 2).

Table 2. FAO guidelines for water use restrictions in irrigation

PARAMETER	RESTRICTION ON USE IN IRRIGATION		
	None	**Mild to moderate**	**Strong**
	Risk of soil salinization		
EC (dS/m)	< 0.7	0.7 – 3.0	> 3.0
TDS (mg/L)	< 450	450 – 2,000	> 2,000
	Risk of reduced soil infiltration rate		
SAR		EC (dS/m)	
0 – 3	> 0.7	0.7 – 0.2	< 0.2
3 – 6	> 1.2	1.2 – 0.3	< 0.3
6 – 12	> 1.9	1.9 – 0.5	< 0.5
12 – 20	> 2.9	2.9 – 1.3	< 1.3
20 – 40	> 5.0	5.0 – 2.9	< 2.9

Source: Adapted from Ayers and Westcot (1985)

The SAR was calculated from the values found for Na, Ca and Mg in milliequivalents per liter, and Equation (1) was used (Bernard; Soares; Mantovani, 2006):

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{++}+Mg^{++}}{2}}} \quad (1)$$

SBA performance analysis was also performed by observing the variation (Var (%)) in the following parameters: apparent color; total dissolved solids; turbidity; ammonia; phosphate; oils and greases; pH; total coliforms; and *E. coli.* To calculate the variation, Equation 2 was used, where C_T corresponds to the concentration of the parameter in the treated gray water and C_B corresponds to the concentration of the parameter in the raw gray water.

$$Var(\%) = \left(1 - \frac{C_T}{C_B}\right) \times 100 \quad (2)$$

For analyses of apparent color, temperature, free residual chlorine and total coliforms, no references were found with VMP recommendations for use in irrigation.

6 RESULTS AND DISCUSSION

6.1 Biowater System Performance

The results presented in Table 3 indicate that the Bioágua system was efficient at reducing turbidity, ammonia, oils, greases, total coliforms and *E. coli*. On the other hand, there was an increase in apparent color, pH and TDS, but the increase in pH values demonstrated the efficiency of the treatment system in making it closer to the neutral pH found in drinking water.

Biowater systems installed in communities in rural areas of the state of Ceará, as analyzed by Barbosa (2019), presented a turbidity reduction efficiency of 82.53% and average turbidity values of 326.81 uT (raw gray water) and 114.94 uT (treated gray water).

In the semiarid region of Paraíba, systems similar to the Bioágua System installed on rural properties in four municipalities presented ammonia concentrations between 0.02 and 5.5 mg/L and phosphate concentrations between 0.09 and 5.55 mg/L (Lopes *et al*., 2021). These values may be due to the use of variable sources of gray water where in most of these systems, gray water originating from kitchen and laundry sinks was used, differing from the system in this research, which only used gray water from the kitchen sink, which may explain the high concentration of phosphate due to the recurrent use of detergent.

When analyzing the treatment efficiency of the Bioágua System installed in Olho d'Água do Borges/RN, Silva *et al*. Unlike in this study, (2018) reported that the pH values of raw gray water were close to the neutral pH value, between 6.55 and 7.66. Regarding the apparent color, the authors reported a minimum value of 215 uC and a maximum value of 240 uC.

Barroso *et al*. (2023), when evaluating the quality of gray water in a family biowater system for agricultural reuse in the Baixo Jaguaribe/CE region, reported, among the 23 samples analyzed, TDS values between 482 and 1,454 mg/L and an average value of 836.42 mg/L.

Table 3. Descriptive statistics (mean, standard deviation, minimum and maximum) of raw and treated gray water samples

	Raw gray water	Treated gray water	Addition ↑ Removal↓
PHYSICAL PARAMETERS			
EC (dS/m)	(1.13 ± 0.34) 0.91 – 1.8	(1.71 ± 0.48) 0.89 – 2.20	-
Apparent color (uC)	(1,011 ± 513) 379 – 1,520	(1,375 ± 1,126) 351 – 2,980	↑ 36.0%
TDS (mg/L)	(740 ± 184) 580 – 1,100	(1,156 ± 425) 630 – 1,754	↑ 56.2%
T (°C)	(30 ± 2.42) 27.2 – 33.3	(30.0 ± 1.10) 27.9 – 31.1	-
Turbidity (uT)	(1,153 ± 734) 238 – 2,230	(141 ± 136) 22.8 – 407	↓ 87.7%
CHEMICAL PARAMETERS			
NH_3 (mg /L)	(26.2 ± 20.5) 0.00 – 55.7	(12.6 ± 13.6) 0.81 – 34.0	↓ 51.7%
Ca (meq/L)	(3.76 ± 2.53) 0.97 – 7.18	(9.27 ± 6.15) 4.01 – 17.3	-
Free residual chlorine (mg/L)	(0.00 ± 0.00) 0.00 – 0.00	(0.00 ± 0.00) 0.00 – 0.00	-
PO_4 (mg/L)	(50.2 ± 80.7) 6.29 – 214	(59.5 ± 86.1) 15.9 – 234	↑ 18.5%
Mg (meq/L)	(1.96 ± 1.32) 0.52 – 3.79	(6.34 ± 2.69) 3.36 – 9.94	-
NO_3 - (mg/L)	(4.60 ± 9.76) 0.00 – 24.5	(4.06 ± 7.31) 0.00 – 18.9	-
NO_2 - (mg/L)	(0.00 ± 0.00) 0.00 – 0.00	(0.00 ± 0.00) 0.00 – 0.00	-
Oils and greases (mg/L)	(2,573 ± 3,543) 978 – 9,800	(600 ± 79.8) 458 - 689	↓ 76.7%
DO (mg/L)	(0.32 ± 0.16) 0.12 – 0.61	(4.99 ± 3.46) 0.49 – 7.97	-
pH	(5.38 ± 0.47) 4.87 – 6.13	(7.05 ± 0.41) 6.52 – 7.58	↑ 31.0%
Na (meq/L)	(13.9 ± 12.2) 5.02 – 36.3	(11.5 ± 1.66) 10.3 – 14.1	-
MICROBIOLOGICAL PARAMETERS			
Total coliforms (CFU/100 ml)	(9,302,533±10,850,266) 1,987,200 – 29,850,000	(610,626 ± 614,490) 1,008 – 1,516,500	↓ 93%
E.coli (CFU/100 ml)	(774,283 ± 315,889) 369,700 – 1,125,000	(43,058 ± 96,300) 29 – 239,500	↓ 94%

Source: Authors (2024)

6.2 Evaluation of treated gray water for use in irrigation

Salinity can reduce the availability of water in the soil and harm plants. Therefore, to assess the total concentration of salts contained in the water intended for irrigation, electrical conductivity was measured. Table III shows that the electrical conductivity of treated gray water presented values between 0.89 dS/m ≤ EC ≤ 2.20 dS/m, which, according to the FAO, is considered water with a mild to moderate degree of use restriction.

In addition to electrical conductivity, the high concentration of total dissolved solids also affects the availability of water for crops. According to the FAO, treated gray water is classified as having a low to moderate level of use restriction, as the TDS values are between 450 and 2,000 mg/L.

With respect to turbidity, the average value in treated gray water exceeded the CONAMA recommendation, which establishes turbidity of up to 100 μT for class 3 fresh water. This also occurred with the average values of ammonia and phosphate concentrations, as the acceptable limit values present in water intended for irrigation are 5 mg/L and 2 mg/L, respectively, according to the guidelines established by the FAO.

According to Barbosa (2019), nitrate is an important nutrient for soil fertility, but if it is found at high concentrations, it becomes harmful to plant development. According to the USEPA, water intended for irrigation with a nitrate concentration of less than 5 mg/L does not have any degree of restriction on use; otherwise, the FAO establishes a concentration of up to 10 mg/L nitrate in water intended for irrigation; therefore, the average value of treated gray water (4.06 mg/L) was satisfactory.

The gray water did not present any nitrite concentration, which is in accordance with the CONAMA resolution, which establishes that the nitrite concentration cannot exceed 1.0 mg/L for class 3 fresh water.

The average concentration of dissolved oxygen in treated gray water was 4.99 mg/L, which is higher than the 4 mg/L recommended by the CONAMA resolution.

According to the FAO, the acceptable pH value of water intended for irrigation is between 6.5 and 8.4; therefore, the average pH value of treated gray water is within the established range (7.05).

The infiltration capacity of water in the soil increases with increasing salinity and decreases with increasing SAR (Bernardo; Soares; Mantovani, 2006). Thus, the degree of restriction of treated gray water intended for irrigation was measured according to the FAO, which guides the analysis of salinity together with SAR, with salinity being expressed by the concentration of electrical conductivity (Table 4).

Table 4. Sodium Adsorption Ratio

Collect	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**
SAR	2.87	2.83	4.05	5.63	6.54	5.60
EC (dS/m)	1.71	1.82	0.89	2.2	2.14	1.51
Degree of restriction (AYERS; WESTCOT, 1985)	None	None	Mild to moderate	None	None	None

Source: Author (2024)

According to the classification of the degree of restriction of water for irrigation established by the FAO, only the treated gray water from collection C3 was classified as having a mild to moderate degree of restriction, distinguishing it from the other collections that presented no degree of restriction for use in irrigation.

According to the limits established by PROSAB and CONAMA for the presence of *E. coli* in water intended for irrigation, the values found in treated gray water exceeded those recommended by these guidelines.

7 CONCLUSIONS

In a scenario of water scarcity, which commonly occurs in arid and semiarid regions, the implementation of sustainable technologies becomes a tool to meet the water demand required by a community.

The biowater system used in this research, as a tool to meet the need for water in irrigation, showed good performance in the treatment of gray water. However, some variations were observed, and no references were found with recommendations of acceptable limits in water for irrigation of the following parameters: apparent color, temperature, free residual chlorine and total coliforms.

SBA made relevant corrections to the quality of raw gray water, since, after treatment, a high reduction rate was observed in turbidity (87.74%), ammonia (51.74%), oils and greases (76.69%), total coliforms (93%), and *E. coli* (94%) and presented pH values close to neutral pH (pH=7), but there was an increase in apparent color and TDS of 36.04% and 56.19%, respectively.

When the average values of the parameters of the treated gray water used to meet the water quality recommendations for use in irrigation were analyzed, it was observed that the values of phosphate and ammonia were discordant with the recommendations of the FAO and that turbidity and *E. coli* were in conflict with the standards established by the CONAMA resolution, with *E. coli* also discordant with the values established by the PROSAB. On the other hand, the values of EC, TDS, nitrate, pH and SAR are in agreement with the values established by the FAO, which are classified as having no degree of use restriction or mild to moderate. The nitrate value is in agreement with that recommended by the USEPA, and the nitrite and DO values are in agreement with those established by CONAMA.

Given the factors observed, it is recommended to install a chlorine disinfection unit for treated gray water before it is used for irrigation and to frequently clean grease traps. In addition, it is essential to regulate the practice of water reuse through regulations with well-established guidelines for acceptable concentrations of each parameter according to multiple nonpotable uses.

8 ACKNOWLEDGMENTS

To the Funding Agency Coordination for the Improvement of Higher Education Personnel (CAPES) for the postgraduate scholarship at the master's level for the author Laíssy Messias dos Santos.

9 REFERENCES

ABNT. **ABNT NBR 16783:** Use of alternative sources of nonpotable water in buildings. Rio de Janeiro: ABNT, 2019.

APHA. **Standard methods for the examination of water and wastewater** . American Public Health Association, American Water Works Association, Water Environmental Federation. 23 ed. Washington, DC: APHA, 2017.

AVSI . **Social Balance Sheet 2022** . Salvador: Plus Comunicação: Carla Piaggio

Design, 2022. Available at: https://www.avsibrasil.org.br/wp-content/uploads/2024/03/balanco-social-avsi-2022-18-07-digital.pdf. Accessed on: April 22, 2024.

AYERS, RS; WESTCOT, DW **Water quality for agriculture** . 29. ed. rev. Rome: FAO, 1985.

BARBOSA, MT **Domestic gray water reuse system for family farming** : the case of rural communities in the state of Ceará. 2019. Dissertation (Master in Science) – Sergio Arouca National School of Public Health, Oswaldo Cruz Foundation, Rio de Janeiro, 2019.

BARROSO, AAF; NASCIMENTO, FJSC; CHAVES, JR; LIMA, PF; SANTOS, HOR Effluent quality in a family Biowater System for agricultural reuse in the Baixo Jaguaribe Region - Ceará. **Brazilian Journal of Irrigated Agriculture** , Limoeiro do Norte, v. 17, n. 1, p. 39-53, 2023.

BERNARDO, S.; SOARES, AA; MANTOVANI, EC **Irrigation manual** . 8th ed. current and expanded. Viçosa: UFV, 2006.

BORGES, LZ **Characterization of gray water to promote the sustainability of water resources** . 2003. Dissertation (Master in Environmental Engineering) – Federal University of Paraná, Curitiba, 2003.

BRAZIL. National Council of the Environment. **CONAMA Resolution No. 357, of March 17, 2005** . Provides for the classification of water bodies and environmental guidelines for their classification, as well as establishing the conditions and standards for the discharge of effluents, and contains other provisions. Brasília, DF: National Council of the Environment, 2005a. Available at: https://www.icmbio.gov.br/cepsul/images/stories/legislacao/Resolucao/2005/res_conama_357_2005_classificacao_corpos_agua_rtfcda_altrd_res_393_2007_397_2008_410_2009_430_2011.pdf. Accessed on: February 16, 2023.

BRAZIL. **Law No. 14,546 of April 4, 2023** . Amends Law No. 11,445 of January 5, 2007 (Basic Sanitation Law), to establish measures to prevent waste, use rainwater and nonpotable reuse of gray water. Brasília, DF: Presidency of the Republic, 2023. Available at: https://www.planalto.gov.br/ccivil_03/_ato2023-2026/2023/lei/L14546.htm. Accessed on: January 9, 2024.

BRAZIL. Ministry of the Environment. National Council of Water Resources. **Resolution No. [54] , of November 28, 2005** . Establishes modalities, guidelines and general criteria for the practice of direct nonpotable reuse of water, and contains other provisions. Brasília, DF: Ministry of the Environment, 2005b. Available at: http://conama.mma.gov.br/index.php?option=com_sisconama&task=documento.download&id=16675 . Accessed on: January 9, 2023.

BRAZIL. Ministry of the Environment. National Council of Water Resources. **Resolution No. [121] , of December 16, 2010** . Establishes guidelines and criteria for the practice of direct nonpotable reuse of water in agriculture and forestry, as defined in CNRH Resolution No. 54, of November 28, 2005. Brasília, DF: Ministry of the Environment, 2010. Available at: https://www.ceivap.org.br/ligislacao/Resolucoes-CNRH/Resolucao-CNRH%20121.pdf. Accessed on: September 18, 2024.

DAGNINO, R. **Social Technology** : a tool for building another society . 2nd ed. and aug. Campinas: KOMEDI, 2010.

ERIKSSON, E.; AUFFARTH, K.; HENZE, M.; LEDIN, A. Characteristics of gray wastewater. **Urban Water** , Kongens Lyngby, v. 4, n. 1, p. 85-104, Mar. 2002. DOI: https://doi.org/10.1016/S1462-0758(01)00064-4. Available at: https://www.researchgate.net/publication/257587685_Characteristics_of_Gray_Wastewater. Accessed on: Feb. 3, 2023.

ESPLAR. Biowater provides production water for families in the backlands of Crateús. **Education for Freedom** , Fortaleza, year 6, n. 6, p. 1-4, 2019. Available at: https://www.calameo.com/read/004290891b262c2cbaf11. Accessed on: April 16, 2024.

GOUVEIA, AR **Construction Manual of the Biowater System** : Sustainable Jucati Project 2: Biowater, Agroecology and Nutrition in the Agreste of Pernambuco. Recife: AVSI Brasil, 2018. Available at : http://www.avsibrasil.org.br/wp-content/uploads/2021/03/Bioagua-Familiar-Manual-de-Construcao-do-Sistema.pdf. Accessed on: April 21, 2024.

GOUVEIA, AR **Biowater System Construction Manual** : Sustainable Pankaiwka Project: Biowater, Agroecology and Nutrition for a Healthy Village. Recife: AVSI Brasil, 2017. Available at : https://transforma.fbb.org.br/storage/socialtecnologies/168/files/Manual%20Construcao%20Bioagua_18.01.2017_AB-IEG_FINAL.pdf. Accessed on: April 17, 2024.

GOUVEIA, AR **System use and maintenance manual Biowater** - Enel Shares Infrastructure Project . Salvador: AVSI Brasil, 2019. Available at : https://www.avsibrasil.org.br/wp-content/uploads/2020/12/GUIA-DO-SISTEMA-BIOA%CC%81GUA-FAMILIAR.pdf. Accessed on: April 17, 2024.

GOUVEIA, AR **User Manual for the Family Biowater System:** Food Security Project for the Semi-Arid Region of Pernambuco . Recife: AVSI Brasil, 2015. Available at: https://www.fbb.org.br/images/Repositorio/07_2017/Manual%20Bioagua.pdf. Accessed on: April 21, 2024.

HE, C.; LIU, Z.; Wu, J.; PAN, X.; FANG, Z.; LI, J.; BRYAN, BA Future global urban water scarcity and potential solutions. **Nature communications** , Beijing , v. 12, no. 4667, p. 1-11, 2021. DOI: https://doi.org/10.1038/s41467-021-25026-3 . Available at: https://www.nature.com/articles/s41467-021-25026-3. Accessed on: September 18, 2024.

IBV. **Family Biowater Manual** : implementation and management of the system. 1st ed. Fortaleza: IBV, 2018. Available at: https://issuu.com/eraldopaulino1/docs/manual_bio_gua_final_web. Accessed on: April 21, 2024.

LOPES, WS; LAMBAIS, GR; NERY, GK M; MELLO, ACP; MEDEIROS, SS; NERY, JF Water quality from alternative sources for multiple uses in the semiarid region of Paraíba. **Geama Magazine** , Campina Grande, v. 7, n. 2, p. 28-38, Aug. 2021.

MENDONÇA, SR; MENDONÇA, LC **Sustainable sewage systems** : technical guidelines for the design and sizing of collection networks, emissaries, channels, pumping stations, treatment and reuse in agriculture . 2nd ed. São Paulo: Blücher, 2017.

NUNES, JA **Biological Treatment of**

Wastewater . 4th ed. rev. updated. and expanded. Aracaju: JA Nunes, 2014.

OTENG-PEPRAH, M.; ACHEAMPONG, MA; DEVRIES, NK Graywater Characteristics, Treatment Systems, Reuse Strategies and User Perception—a Review. **Water, Air, and Soil Pollution** , Maastricht, v. 229, no. 255, jul. 2018. DOI: https://doi.org/10.1007/s11270-018-3909-8 . Available at: https://link.springer.com/article/10.1007/s11270-018-3909-8. Accessed on: 03 Feb. 2023.

PINTO, GO; SILVA JUNIOR, LCS; ASSAD, DBN; PEREIRA, SH; MELLO, LCBB Trends in global graywater reuse: a bibliometric analysis. **Water Science and Technology** , Rio de Janeiro, v. 84, n. 10/11, p. 3257-3276, 2021. DOI: https://doi.org/10.2166/wst.2021.429 . Available at: https://iwaponline.com/wst/article/84/10-11/3257/84373/Trends-in-global-graywater-reuse-a-bibliometric. Accessed on: March 18, 2024.

PROSAB. **Treatment and use of sewage** . 1st ed. Recife: ABES, 2006.

SANTIAGO, F.; JALFIM, F.; BLACKBURN, R.; DOMBROSKI, S.; MONTEIRO, L.; NANES, M; DIAS, I.; GURGEL, R.; OLIVEIRA, B.; OLIVEIRA, O.; SANTOS, W.; PINHEIRO, MR; SALES, F.; SILVA, J. **Manual for implementation and management of the Family Biowater System** : Reuse of domestic gray water for food production in family farming in the Brazilian semiarid region . 1st ed. Caraúbas: ATOS, 2015.

SANTOS, VC Implementation of two **graywater reuse systems to promote productive backyards in the semiarid region of Northeast Brazil.** 2020. Course Completion Work (Bachelor's Degree in Agricultural Engineering) – Federal University of Sergipe, São Cristóvão, 2020.

SERHMA. **Digital Atlas on Water Resources of Sergipe** . Aracaju: SERDUBS, 2020.

SILVA, EAAD; SILVA, FE; SILVA, MELD; ASSUNÇÃO, MDSL Efficiency of the Biowater System in the Treatment of Gray Water . *In* : BRAZILIAN CONGRESS OF ENGINEERS WITHOUT BORDERS, 5th, Natal, 2018. **Proceedings** [...]. Natal: ESF Brasil, 2018. p. 1-9.

USEPA. **2012 Guidelines for Water Reuse** . Washington, DC: EPA, 2012. Available at: https://www.epa.gov/sites/default/files/2019-08/documents/2012-guidelines-water-reuse.pdf. Accessed: February 15, 2023.

World Health Organization. **Guidelines for the safe use of wastewater, excreta and graywater** : Excreta and graywater use in agriculture. Geneva: WHO, 2006. Available at : https://www.who.int/publications/i/item/9241546859. Access on : 01 Mar 2023.

World Health Organization. **Reuse of effluents** : methods of wastewater treatment and health safeguards . Geneva: WHO, 1973. (Technical report series, n. 517).