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Municipal sewage treatment for non-potable urban reuse in the Brazilian semiarid

The Brazilian semi-arid region has less water available than its demand, which can affect the development of activities in the urban, industrial and agricultural sectors. In addition, in this region, about 80% of the sanitary sewage is released into the environment without treatment, causing immense negative environmental impacts, mainly due to the degradation of water quality. The city of Campina Grande-PB is considered the 'city of innovation', however, until now the collected sewage is treated by a system composed of stabilization ponds, widely used in the Brazilian Semiarid, but the effluent of this type of ponds is not suitable for urban and industrial reuse. This work studied an alternative sewage treatment system for sanitary sewage in the city of Campina grande-PB, aiming to produce water suitable for non-potable urban reuse. The sewage treatment system removed almost 100% of the indicators on faecal contamination and about 90% of the COD. When compared to the parameters of current legislation, the effluent is suitable for urban reuse, and can be used for washing cars, squares, street markets, sidewalks, patios, floors; discharge of toilet; construction; landscaping; garden irrigation; and others. This type of initiative can decrease the use of better quality water resources, increasing water availability for the region's development.

Keywords: Sewage treatment; Urban reuse; Semiarid; Water reuse.

Tratamento de esgoto municipal para reúso urbano não potável no semiárido brasileiro

O semiárido brasileiro possui menos água disponível do que sua demanda, o que pode afetar o desenvolvimento de atividades nos setores urbano, industrial e agrícola. Além disso, nesta região, cerca de 80% do esgoto sanitário é lançado no meio ambiente sem tratamento, causando imensos impactos ambientais negativos, principalmente pela degradação da qualidade da água. A cidade de Campina Grande-PB é considerada a 'cidade da inovação', porém, até o momento o esgoto coletado é tratado por um sistema composto por lagoas de estabilização, muito utilizado no Semiárido brasileiro, porém o efluente deste tipo de lagoas não é adequado para reutilização urbana e industrial. Este trabalho estudou um sistema alternativo de tratamento de esgoto para esgotamento sanitário na cidade de Campina grande-PB, visando a produção de água adequada para reúso urbano não potável. O sistema de tratamento de esgoto removeu quase 100% dos indicadores de contaminação fecal e cerca de 90% da DQO. Quando comparado aos parâmetros da legislação vigente, o efluente é adequado para reaproveitamento urbano, podendo ser utilizado para lavagem de carros, praças, feiras livres, calçadas, pátios, pisos; descarga de vaso sanitário; construção; paisagismo; irrigação de jardins; e outros. Esse tipo de iniciativa pode diminuir o uso de recursos hídricos de melhor qualidade, aumentando a disponibilidade hídrica para o desenvolvimento da região.

Palavras-chave: Tratamento de esgoto; Reutilização urbana; Semiárido; Reuso de água.

Topic: **Tecnologia, Modelagem e Geoprocessamento**

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INTRODUCTION

The Brazilian semiarid region is characterized by a short rainy period and irregular distribution of precipitation, high temperatures, high evaporation rates, shallow soils, intermittent rivers and scarce underground water resources (MONTENEGRO et al., 2012; SOUSA et al., 2005), that causes high water vulnerability, with economic and social impacts.

Water is a limiting factor for urban, industrial and agricultural development. Even areas with ample water resources, but insufficient to meet high demands, experience conflicts of use and suffer consumption restrictions that affect people's economic development and quality of life. In this reality, urban reuse stands out in the management of water resources, as it is capable of reducing conflicts and mitigating water vulnerability, in addition to contributing to the environmental conservation (HESPANHOL, 2002).

The production of raw sewage in the Brazilian semiarid reached 423 million $m^3.year^{-1}$. The volume of sewage collected accounted, however, for only 117 million $m^3.year^{-1}$, approximately 28%. Finally, the volume of treated sewage was limited to 89 million $m^3.year^{-1}$, which is equivalent to 21% of the sewage produced in the Brazilian semiarid region (MEDEIROS et al., 2014). In this way, the universalization of sanitation in the Brazilian semiarid will enable the exploitation of an enormous potential of treated sewage, for urban, industrial and agricultural reuse, a valuable and little explored resource in the region.

The collect, transportation, treatment and proper disposal of wastewater generated by human activity, in which sewage has a prominent place, constitutes one of the actions that most positively impact the quality of life of the population. Without treatment, sewage is a potential source of disease and pollution of water bodies, making them unsuitable for the noblest uses, such as public and industrial supply.

In this context, sewage treatment is essential to improve public health, environmental quality and reused water production. This alternative source of water can contribute significantly to the water demand in the Brazilian semiarid region (METCALF & EDDY, 2003; GHEYI et al., 2012). However, the reuse of treated sewage effluents is still incipient in the region, being limited to pilot projects, urgently needing expansion and insertion with the sectorial and management bodies, in addition to the inclusion in new environmental sanitation projects at the state and federal levels (CIRILO, 2010).

The choice of this adequate sewage treatment system for the production of reused water depends, mainly, on the financial availability, the quality of the desired effluent and the characteristics of the region where it will be installed. There are countless types of sewage treatment systems used in the world and in the semiarid region of Brazil. However, since the 1970s, the UASB reactor system has become one of the most recognized, mainly for countries that have few resources and a hot climate (KHAN et al., 2011). This is due to the advantages that this system presents, such as: low implantation cost, energy recovery in the form of biogas, ease of operation, small demand for area and low sludge production, which comes out densified and stabilized (VAN HAANDEL et al., 1994; CHERNICHARO, 2007).

According to Rocha et al. (2009), despite the great advantages of using anaerobic processes for wastewater treatment, there are also some disadvantages. Among them, the potential to generate odors, corrosive gases, low pathogen removal and the need for post-treatment are highlighted. These disadvantages are even more worrying when there is a need to implement UASB reactors close to urban occupations, because hydrogen sulfide is a toxic compound (MAINIER et al., 2005). In addition, it is capable of causing corrosion, and even creates odor problems around the facilities where it is produced (BARBOSA et al., 2019).

There are several types of effluents after-treatments from UASB reactors, such as soil disposal, polishing ponds, biofilm reactors, activated sludge, biological filter, filtration systems and disinfection systems. Generally, after an anaerobic treatment, an aerobic treatment is used and, depending on the quality of the desired effluent, filtration and disinfection can be used (VAN HAANDEL et al., 2012; VON SPERLING, 2005). Among the existing aerobic treatments, the activated sludge system has been gaining prominence, mainly due to the high quality effluent and low demand for implantation area (VAN HAANDEL et al., 2012; VON SPERLING, 2005). Over the years, variants of conventional activated sludge have arisen, one of the most common, is to use a single tank to carry out all stages of the process, primary sedimentation, biological oxidation and sedimentation in a sequential manner; this describes the sequential batch activated sludge reactor – SBR (VAN HAANDEL et al., 1999).

According to Paiva (2016), the use of SBR is an efficient alternative for removing residual organic material from the effluent of UASB reactors, and there is still the possibility of removing ammonia, phosphorus and helminth eggs. In his research, the system reduced helminth eggs by 70%, which went from an average of 23 eggs.L^{-1} to 6 eggs.L^{-1}.

In view of this reality, this work intends to produce a quality effluent for non-potable urban reuse, treating sanitary sewage of the municipality of Campina Grande-PB, using an association between UASB reactor followed by SBR, with subsequent filtration and disinfection with chlorine.

METHODOLOGY

The treatment system studied on a laboratory scale had the sanitary sewage as a tributary, collected in the interceptor of the eastern sector operated by Paraíba Water and Sewage Company, responsible for the sanitary sewage system in the city of Campina Grande-PB. The sewage was forced by a submerged pump (ANAUGER-800) to a storage tank with a volume of 2 m^3, provided with a mechanical stirrer to promote homogenization before pumping into the treatment system.

Experimental treatment system

The sewage treatment system consisted of UASB reactor, Equalization Tank (TE), Sequential Batch Reactor (RBS), Sand Filter (FA) and Chlorination Tank (TC), shown in Figure 1. All electrical operating commands were planned and programmed, using digital timers (100-240), providing more operational security and autonomy to the municipal sewage treatment system.

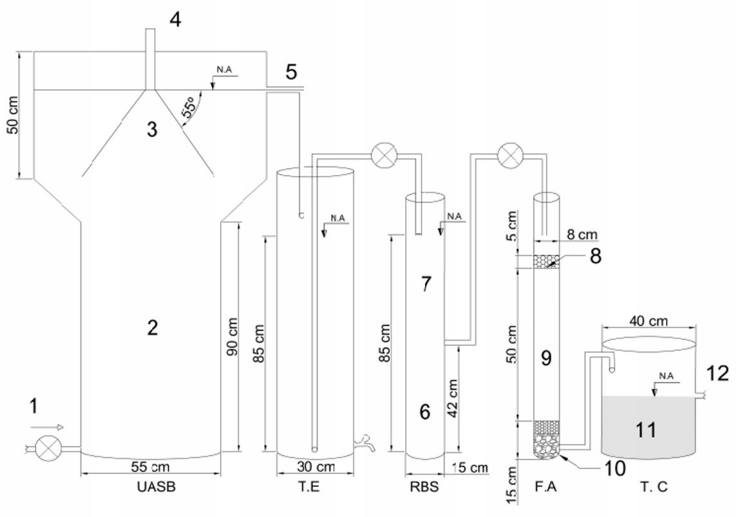

Figure 1: Sewage treatment system for non-potable urban reuse.
1 – Affluent; 2 – Active anaerobic digestion zone; 3 – Conical three-phase separator; 4 – Biogas output; 5 – UASB reactor effluent; 6 – Place where aerobic sludge settles; 7 – Place where the clarification happens; 8 – Gravel layer n°3; 9 – Sand layer (0.3 mm); 10 – Gravel and rubble; 11 – Liquid in contact with chlorine; 12 – Effluent ready for urban reuse.

Upflow Anaerobic Sludge Blanket (UASB)

The UASB used in this research follows the model of Santos et al. (2017), it has been built in fiberglass, with PVC connections and a volume of 250 L, being designed to treat 500 L.d^{-1} of sewage and to operate with Hydraulic retention time (HRT) of 12 hours. Its constructive characteristics are detailed in Figure 1.

The UASB power supply used an electromagnetic metering pump (MF-DLXB-MA/AD), operating continuously. The effluent from this reactor was collected in a 500 L PVC box, from where it was repressed to the RBS by an electric pump.

Sequential Batch Reactor (RBS)

The RBS was built in PVC and its construction features are detailed in Figure 1. The supply, disposal and aeration of this reactor were controlled by digital timers (100-240), taking place in an automated way. The UASB effluent was pumped by an electric pump feeding the activated RBS for 1 min, providing a volume of 8 L. This tributary mixed with the active sludge and formed a mixed liquor, remaining in aeration for 2 hours. After that time, the aeration was turned off for 25 min, to allow the sedimentation of the sludge and clarification of the effluent. After this process, an electric pump moved the treated effluent to the sand filter.

Filtration

The sand filter was made of transparent acrylic in a cylindrical shape, filled with 10 cm of rubble layer, 10 cm of gravel layer and 40 cm of sand layer, forming a filtration column. Their specificities are shown in Figure 1.

Chlorination

Chlorine disinfection was chosen because it is an easy acquisition and low cost method, in addition to providing residual chlorine in the treated effluent. Calcium hypochlorite (40%) is one of the most used compounds in the disinfection of wastewater from sewage treatment plants. In this research, a chlorination tank with a volume of 80 L, made of PVC, was used, where 0.01 g Calcium hypochlorite [$Ca(ClO)_2$] was added to each liter of treated effluent, providing an active chlorine concentration of 4 $mg.L^{-1}$. Chlorine was added and mixed, remaining in contact for 30 minutes. Subsequently, the effluent was discarded to start a new batch of chlorination. Jordão et al. (2011) recommend a dosage of 2.0 to 8.0 $mg.L^{-1}$ for activated sludge effluents, and a minimum residual chlorine of 0.5 $mg.L^{-1}$ after 30 min of contact. They verified a linearity in the content of total residual chlorine (TRC) for dosages up to 12 $mg.L^{-1}$ of chlorine; for dosages of 5, 6 and 7 $mg.L^{-1}$, they found TRC concentrations of approximately 2.25, 3.5 and 4.75 $mg.L^{-1}$, respectively. Thus, the concentration of 10 $mg.L^{-1}$ of calcium hypochlorite (40%), used in the chlorination process, should be able to produce an effluent with TRC greater than 0.5 $mg.L^{-1}$.

Monitoring of physical-chemical and microbiological parameters

The monitoring of the experimental sewage treatment system was implemented to control the operational conditions of the reactors and to ascertain the quality of the effluent produced for non-potable urban reuse. The parameters in Table 1 started monitoring in August 2018, while the parameters in Table 2 started monitoring in May 2019, both completed in July 2019. Laboratory analyzes were performed weekly, right after sample collections.

Table 1: Physical-chemical parameters.

Parameters that measure UASB performance		
Variables	**Method**	**Reference**
*COD ($mg.L^{-1}$)	Titration	5220 C./APHA et al. (2012)
Total alcalinity	Kapp	BUCHAUER (1998)
*pH	Potentiometric	APHA et al. (2012)
Parameters that measure RBS performance		
Ammonia ($N\text{-}NH_4^+$)	Semi-MicroKjeldahl	4500-NH_3/APHA et al. (2012)
Nitrate ($N\text{-}NO_3^-$)	Sodium salicylate	SILVA et al. (2001)
Nitrite ($N\text{-}NO_2^-$)	Colorimetric	4500-NO_2 B/APHA et al. (2012)
*COD ($mg.L^{-1}$)	Titration	5220 C./APHA et al. (2012)
DO ($mg.L^{-1}$)	Electrometric	Multi-parameter meter

* COD – Chemical Oxygen Demand; DO – Dissolved oxygen; pH – Hydrogenionic potential.

In order to analyze more important parameters in the effluent quality for non-potable urban reuse, the monitoring of the parameters contained in Table 2 was contemplated. Thus, the quality parameters of the treated sewage are presented in Tables 1 and 2.

The monitored parameters were compared with those recommended in the ABNT NBR 13.969/1997, and with the joint resolution SES/SMA/SSRH nº 01, of June 28, 2017, aiming to ascertain the quality of the treated sewage for urban reuse in the city of Campina Grande-PB. This model could serve as a basis for replication in other municipalities in the Brazilian semiarid, contributing to the water strengthening of the region.

Table 2: Quality parameters of the final effluent.

Variables	Method	Reference
Temperature (ºC)	-	APHA et al. (2012)
*pH	Potentiometric	APHA et al. (2012)
*DO ($mg.L^{-1}$)	Electrometric	Multi-parameter meter
Salinity (%)	Potentiometric	Multi-parameter meter
Conductivity ($mS.cm^{-1}$)	Potentiometric	Multi-parameter meter
Turbidity (NTU)	Nephelometric	APHA et al. (2012)
*TDS ($mg.L^{-1}$)	Potentiometric	Multi-parameter meter
Color	Colorimetric	APHA et al. (2012)
Escherichia coli	Colilert®	APHA et al. (2012)
Helminth eggs	BAILENGER modified	BAILENGER (1979) modified by AYRES et al. (1996)
*BOD_5 ($mg.L^{-1}$)	Titration	APHA et al. (2012)
TRC ($mg.L^{-1}$)	Colorimetric	APHA et al. (2012)

* DO – Dissolved oxygen; pH – Hydrogenionic potential; TDS – Total dissolved solids; BOD – Biochemical oxygen demand; TRC – Total residual chlorine.

RESULTS AND DISCUSSION

Operational evaluation of the UASB reactor

The parameters used for the operational balance of the UASB reactor were pH and alkalinity. Analyzing the values and averages found of 7.7 and 420 mg $CaCO_3.L^{-1}$, respectively, we can say that there are no signs of instability on the anaerobic digestion. This is confirmed when observing the values of Chemical Oxygen Demand (COD) on the affluent and UASB reactor effluent, generated in Figure 2.

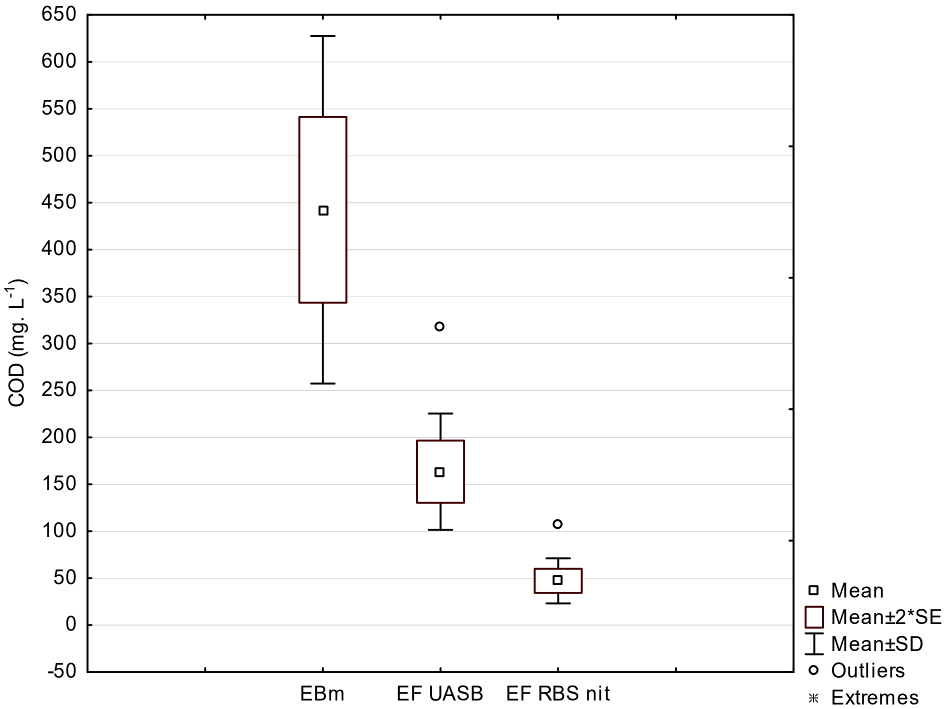

Figure 2: COD results for municipal raw sewage (EBm), UASB effluent (EF UASB) and RBS effluent (EF RBS nit).

The raw sewage of Campina Grande city, during the period from July to November 2018, presented an average concentration of organic matter of 442 ± 185 $mgO_2.L^{-1}$, while the UASB reactor effluent presented an average of 163 ± 62 $mgO_2.L^{-1}$, causing a removal efficiency of 63%, that is in line with those found by Sousa et al. (2016) and Barbosa et al. (2019).

Operational evaluation of the RBS reactor

Sequential batch reactors, when treating raw sewage, have high organic matter removal efficiencies, generally above 90%. However, in this research the sewage goes through a UASB, having its composition altered during anaerobic digestion. In common raw sewage, the N/COD and P/COD ratio are in the range of 0,10 mgN/mgDQO and 0,025 mgP/mgDQO. After anaerobic digestion in the UASB reactor, these proportions became about 0,3 mgN/mgDQO and 0,05 mgP/mgDQO, since 63% of COD and little of the concentrations of N and P were removed. When added to the fact that soluble and easily biodegradable COD is removed in the UASB, a timid removal of organic matter in the RBS was expected, however, the average efficiency was 71%, producing an effluent with an average COD of 46 $mgO_2.L^{-1}$. Paiva (2016) studied the efficiency of RBS reactor as after-treatment of effluents from UASB reactors, and found average COD removal efficiencies of 70% and 65%.

The RBS, as a post-treatment of UASB reactors effluent, raises his quality, mainly in relation to the removal of organic matter, solids and ammoniacal nitrogen. Paiva et al. (2020) carried out an experimental investigation that showed conclusively that the activated sludge system of the RBS type is a very efficient alternative in the removal of suspended solids and residual organic materials from UASB reactors effluent that treat domestic sewage. Regarding the removal of ammoniacal nitrogen, the average removal efficiency was 71%. The affluent and effluent nitrogen fractions averages are shown in Figure 3.

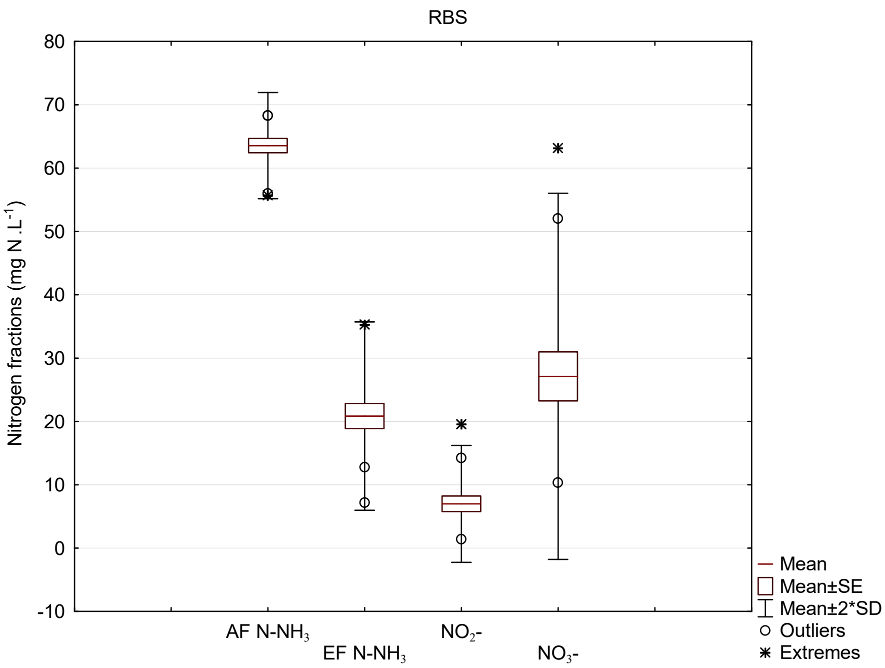

Figure 3: Results of monitored nitrogen fractions.

The average concentration of ammoniacal nitrogen present in the UASB effluent was 62,3 ± 4,6 mg $N\text{-}NH_4.L^{-1}$; after RBS it was 18,3 ± 9,1 mg $N\text{-}NH_4.L^{-1}$; after chlorination, this value became 14,5 ± 4,5 mg $N\text{-}NH_4.L^{-1}$. Thus, the concentration of ammoniacal nitrogen is within the recommended by CONAMA Resolution 430/2011, for release in water bodies. Ammonia affluent to RBS was oxidized to nitrite and nitrate, with averages of 7,8 ± 4,8 mg $N\text{-}NO_2.L^{-1}$ and 26,6 ± 5,7 mg $N\text{-}NO_3.L^{-1}$ in the RBS effluent with a sludge age of 10 days.

The use of RBS can cause sudden concentrations of solids suspended in the effluent. To avoid this presence and improve microbiological quality, a sand filter was used after the RBS, capable of removing suspended particles, including helminth eggs.

All of these steps reduce the concentration of bacteria present in the sewage, but to meet the standards required by urban reuse legislation, a disinfection step is usually necessary, capable of allowing the presence of remaining active chlorine in the effluent. In this study, chlorination with a dosage of 0,01 g Calcium hypochlorite [$Ca(ClO)_2$] per liter of treated efluente, performed under manual agitation, was sufficient to provide a concentration of total residual chlorine (TRC) in the effluent ranging from 0,5 to 1,0 mg/L.

Chlorine disinfection has high efficiency, which in this case, was proven by the results of microbiological analyzes, because in 80% of the samples the *Escherichia coli (E. coli)* bacteria were not found, and in the 20% of the samples the concentration of this indicator ranged from 0 to 1,0 NMP/100mL.

Based on these results, we can say that the proposed sewage treatment system operated with stability and efficiency, showing his functionality for the treatment of municipal sewage, especially when the objective is to reuse the water produced in an urban environment.

Evaluation of the final quality of the effluent for urban reuse in the Brazilian semiarid region

In Brazil, there is still no specific federal law on the criteria and standards required for water, for urban reuse. However, some municipalities and states have laws that deal with the topic, such as the city of São Paulo-SP, Maringá-PR and the state of São Paulo-SP, through laws nº 6.076/2003, nº 1.674/2015 and Joint Resolution SES/SMA/SSRH nº 01 of June 28, 2017, respectively. These laws and the resolution regulate the direct non-potable reuse of water, for urban purposes, from Sanitary Sewage Treatment Stations, and provide other related measures.

The state of São Paulo is one of the first in the country to carry out urban reuse; this practice has been taking place successfully, however, the need for legal regularization was urgent and ended up serving as an example for other states, especially those inserted in the semi-arid region of the country, where urban reuse is increasingly necessary.

At the national level, there is the Brazilian Association of Technical Standards (ABNT), which published NBR 13.969/1997, which defines the minimum parameters to be met for non-potable urban reuse. Therefore, the results obtained were compared with the main parameters recommended by this standard and by the Joint Resolution SES/SMA/SSRH Nº 01, of June 28, 2017, as this resolution is more demanding than most of the legislation used in several countries of the world, when referring to urban reuse. A summary of the results and comparison values are shown in Table 3.

The rules, laws and resolutions on water reuse use physical-chemical and microbiological evaluation parameters, to guarantee the quality of the water produced and sanitary safety, seeking to fit the reused water to its demands. However, some monitoring parameters vary between rules, laws and resolutions, especially with regard to microbiological parameters, which some take into account the most likely number (NMP/100 mL) of temortolerant coliforms (TTC), faecal coliforms (FC), total coliforms (TC) and *Escherichia coli* (*E. coli*). In the case of NBR 13.969/1997 and Resolution SES/SMA/SSRH nº 01/2017, they use FC and TTC, respectively.

Table 3: Synthesis of the results obtained in the research in comparison with the NBR 13.969/1997 and the resolution SES/SMA/SSRH nº 01/2017.

Parameters	Campina Grande-PB treated sewage	NBR 13.969/1997			SES/SMA/SSRH 01/2017
		Class 1	**Class 2**	**Class 3**	**Severe restricted use**
Turbidity (NTU)	2,5 ± 1,1	< 5	< 5	< 10	-
Fecal Coliforms (NMP/100mL)	-	< 200	< 500	< 500	-
Thermotolerant Coliforms (NMP/100mL)	-	-	-	-	< 200
E.Coli (NMP/100mL)	0,1 ± 0,3 Absent in 80% of samples				< 120
TDS (mg/L)	1200 ± 200	< 200			
TSS (mg/L)	--				≤ 30
pH	7,9 ± 0,4	6,0 - 9,0			6,0 – 9,0
TRC (mg/L)	5 > TRC > 1	0,5 -1,5	> 0,5		≥ 0,5
BOD (mg/L)	---				≤ 30
Oils and greases (mg/L)	Virtually absent				
Color (CU)	80,2 ± 18,5				
Helminth eggs (egg/L)	Absent in 100% of samples				≤ 1 egg/L
Chlorides (mg/L)	141,5 ± 54,9				<350
Conductivity (mS/cm)	1,7 ± 0,3				<3
E.Coli (NMP/100mL)	0,1 ± 0,3 Absent in 80% of samples				< 120
Salinity (%)	0,1 ± 0,0				
DO (mg/L)	5,3 ± 0,5				
COD (mg/L)	46,1 ± 25,6				
Nitrate (mg/L)	26,6 ± 5,7				
Nitrite (mg/L)	7,8 ± 4,8				
Ammonia (mg/L)	11,1 ± 6,2				

Source: Adapted from NBR 13.969/97 and joint resolution SES/SMA/SSRH nº 01/2017.
NBR 13.969/97: Class 1 - Car wash, other uses that require direct user contact with water and fountains; Class 2 - Cleaning of floors, sidewalks and irrigation of gardens and landscaping purposes; Class 3 - Sanitary discharges. SES/SMA/SSRH (2017): Landscape irrigation, washing of public places, civil construction, unblocking of rainwater galleries, sewage network and washing of special vehicles.

During this work, the monitoring of microbiological quality used the most likely number of *Escherichia coli* as a parameter. When the NMP/100mL of *E. coli* is lower than the NMP/100mL of TTC, FC and TC required by law, this indicates that the effluent is within the required standards. Thus, analyzing the data presented in Table 3, we can say that the quality of the effluent produced, from the sanitary sewage treatment of Campina Grande-PB, is suitable for the main types of urban reuse provided in NBR 13.969/1997 and in Resolution SES/SMA/SSRH nº 01/2017.

For class 1 reuse, according to NBR 13.969/1997, the amount of TDS is above the recommended amount, however these high TDS values are characteristic of the supply water in the city of Campina Grande-PB. In addition, the TDS parameter is not required by SES/SMA/SSRH nº 01/2017, nor by CONAMA Resolution 430/2011 and by most laws used in other countries, as is the case of official Mexican standards (NOM-001-

SEMARNAT-1997).

If there is an interest in removing these total dissolved solids, it is necessary to use advanced sewage treatment techniques, such as reverse osmosis, which would result in increased costs, however, it would produce a high quality effluent, which could be used to meet the noblest uses and water demands of the industry.

CONCLUSIONS

The sewage treatment system for non-potable urban reuse produced an effluent with physical-chemical and microbiological quality that fits the requirements of most urban and industrial non-potable uses in the Brazilian semiarid region.

The treated effluent obtained characteristics that exceed the water quality of some water bodies in the Brazilian semiarid, especially during the dry season, which reinforces the potential and the need for sewage treatment for urban, industrial and agricultural reuse.

The results also showed the importance of implementing this system for the production of sewage treated at full scale, aiming to meet the urban demands of cities in the Brazilian semiarid region, strengthening the region's water potential.

The quality of the effluent allows its use in industry for less noble uses. If there is an interest in carrying out industrial reuse in more demanding processes, it is recommended to use advanced sewage treatment, complementing the system with the use of reverse osmosis.

Sewage treatment for reuse is an important tool for the management of water resources, especially in the Brazilian semiarid region, making it possible to direct drinking water to more demanding uses, increasing water availability and reducing social conflicts over the use of water.

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