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Adaptation of domestic effluent for agricultural reuse by biological, physical treatment and disinfection by ultraviolet radiation

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ABSTRACT

Domestic effluent reuse is an alternative for irrigated agriculture in situations of reduced water availability. However, as there is the presence of pathogens in wastewater, the disinfection process is necessary before use. This research evaluated the sanitary and agricultural viability of treated wastewater at a pilot-scale station composed of a septic tank, *Wetlands* and an ultraviolet radiation (UV) disinfection system. The Sewage Treatment Station (STS) is installed in the Agricultural Sciences Center, UFSCar, in Araras city, SP, and receives 2000 L of sewage daily, which was monitored in terms of pH, turbidity, electrical conductivity (EC), dissolved oxygen (DO), sodium (Na), potassium (K), calcium (Ca), total nitrogen (TN), total phosphorus (TP), magnesium (Mg), total organic carbon (TOC), total coliforms (TC), *Escherichia coli* (*E. coli*) and Sodium Adsorption Ratio (SAR).The removal efficiency of the parameters was calculated based on the input and output means of each treatment unit. Results indicated removal efficiency for K (68.2%), TN (54.1%) and TP (36.1%). The levels of Na (26.7%) and Ca (22.9%) demonstrated the contribution of these salts to the wastewater; however, SAR did not present any risks for soil sodification. Microbiologically, the STS presented removal efficiency of 4 and 5 log-cycles for TC and *E. coli*, respectively. Therefore, results of monitoring indicate that the treated wastewater presents sanitary and agricultural viability, and conforms with the current legislation.

Keywords: nutrients, sewage, ultraviolet radiation.

Adaptação de efluente doméstico para uso agrícola por tratamento biológico, físico e desinfecção por ultravioleta

RESUMO

O reúso de efluente doméstico é uma alternativa para a agricultura irrigada em situações de reduzida disponibilidade de água. No entanto, como é comum a presença de patógenos em águas residuárias, torna-se necessário um processo de desinfecção previamente à sua utilização. Com o desenvolvimento da pesquisa, avaliou-se a viabilidade sanitária e agrícola do efluente doméstico tratado em Estação Piloto composta por Tanque Séptico, *Wetlands* e sistema de desinfecção por radiação ultravioleta (UV). A Estação de Tratamento de Esgoto (ETE) se encontra instalada no Centro de Ciências Agrárias, UFSCar, em Araras-SP, e recebe diariamente 2000 L de esgoto, o qual foi monitorado em termos de pH, turbidez, condutividade elétrica (CE), oxigênio dissolvido (OD), sódio (Na), potássio (K), cálcio (Ca), nitrogênio total (NT), fósforo total (PT), magnésio (Mg), carbono orgânico total (COT), coliformes totais (CT), *Escherichia coli* (*E. coli*) e Razão de Adsorção de Sódio (RAS). A eficiência de remoção dos parâmetros foi calculada com base nas médias de entrada e saída de cada unidade de tratamento. Os resultados apontaram remoção para K (68,2%), NT (54,1%) e PT (36,1%). Os teores de Na (26,7%) e Ca (22,9%) demonstraram aporte desses sais ao efluente, porém, a RAS não apresentou riscos quanto à sodificação do solo. Com relação aos microbiológicos, a ETE apresentou uma remoção de 4 e 5 ciclos log para CT e *E. coli*, respectivamente. Sendo assim, os resultados do monitoramento indicam que o efluente tratado da ETE Piloto apresenta viabilidade sanitária e agrícola, estando de acordo com a legislação vigente.

Palavras-chave: esgoto, nutrientes, radiação ultravioleta.

1. INTRODUCTION

Population growth, climatic instability and increased demand for food culminated in the scarcity of water of adequate quality to irrigate agriculture (Ahmadi and Merkley, 2017). One of the strategies to ameliorate the water crisis is to invest in the reuse of effluents, which can intensify agricultural production even during off-season periods (Hespanhol, 2008).

Recycling nutrients in agriculture is a sustainable strategy since it minimizes the pollution of aquatic environments and decreases the dependence on mineral fertilizers (Pantano *et al.*, 2016).

However, the practice of reuse with effluents requires treatment steps that are allied with its purpose and application. The most commonly used systems employed for this are septic tanks and *Wetlands*.

New techniques are being studied in order to improve/increase the efficiency of removal of organic matter, salts and pathogens from Septic Tanks, employing the use of anaerobic reactors filled with zeolites modified with copper (Anil and Neera, 2016) or with the installation of electrodes of stainless steel (Lin *et al.*, 2017).

Increasingly, *Wetlands* are been implemented for the treatment of effluents from cleaning trucks, septic tanks, chemical toilets and even grease residues. A simple method, but one that requires caution as to its required efficiency, in order not to cause imbalances, such as low disinfection efficiency due to the inhibition of ultraviolet rays (Andrade *et al.*, 2017).

Treatment systems are designed according to removal efficiency, thus enabling the disposal of the effluent. Souza *et al.* (2015) developed a pilot-scale station consisting of a septic tank, anaerobic filter, microalgae tank and *Wetlands*, and noted that these associated units removed part of the essential nutrients for agriculture. In addition, there was an impediment to such application: the expressive presence of bacterial from the Coliform class.

In this sense, a disinfection as tertiary treatment becomes essential, considering the high burden of pathogens usually present in domestic effluents, in order to ensure the integrity of human health (Zhou *et al.*, 2015).

One of the options used for sewage disinfection is the application of the ultraviolet system (UV), which is based on electromagnetic radiation and wavelengths less than violet light, without the generation of by-products harmful to health or the release of residuals to the wastewater.

Fluorescent lamps responsible for the emission of UV radiation have in their interior a tube coated with phosphorus powder containing gas (argon type) and mercury. From an electrical potential difference, the electrons fluxes collide with the mercury atoms providing the UV light, which is absorbed by the phosphorus becoming visible (Salvetti, 2008).

Microorganisms are inactivated by the action of UV radiation, which causes damage to nucleic acids, macromolecules responsible for carrying genetic information (deoxyribonucleic acid - DNA) and protein synthesis (ribonucleic acid - RNA) (USEPA, 2003).

According to Regulatory Brazilian Standard NBR 13.969 (ABNT, 1997), the irrigation technique for some crops with the reuse of treated wastewaters is classified as Class 4 and may be destined to orchards, cereals, fodder, cattle pastures and other crops through surface runoff or point irrigation. Considering the World Health Organization (WHO, 2006) the types of irrigation can be:

- Restricted: cultures cannot be ingested raw, or unprepared, with the maximum of 10^5 allowed of *Escherichia coli* in 100 mL in the treated wastewater and;
- Unrestricted: can be consumed without pre-preparation with a total of 10^3 of *Escherichia Coli* in 100 mL of treated wastewater.

The perspective of sustainable development proposes the use of treated wastewaters in irrigated agriculture. However, the pathogenic load of sewage is high and may interfere with the advancement of this technique, causing sanitary problems to an extensive population through food and contaminated soil. The incidence of UV radiation in the treated wastewater is mainly aimed at microbiological reduction, especially that of the group of total coliforms and *Escherichia coli*.

Thus, the objective of the research was to evaluate the sanitary and agricultural viability of a treated domestic effluent, from a Sewage Treatment Station composed of the septic tank units, *Wetlands*, and UV disinfection.

2. MATERIAL AND METHODS

2.1. Pilot system of treatment of domestic sewage

Pilot Sewage Treatment Station (STS) is installed and operating at the CCA (Center of Agricultural Sciences - Federal University of São Carlos) in Araras city, State of São Paulo, latitude 220 18'53.23" South, and longitude 470 23'00.91" West; to 701 m of altitude. With Cwa type-subtropical climate and average annual precipitation of 1300 mm (Souza *et al.*, 2015). The STS was designed to receive daily volumes of 2000 liters of wastewater from the refectory and bathrooms of the University. Figure 1 shows a schematic of the arrangement of its treatment steps.

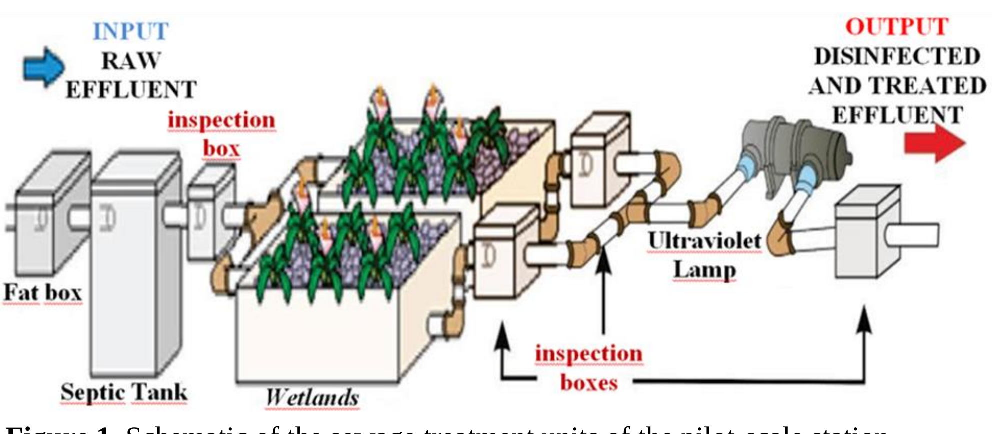

Figure 1. Schematic of the sewage treatment units of the pilot-scale station.
Source: Adapted from Souza *et al.* (2015).

In this way, the wastewater treatment system consisted of:

- Fat box: with a capacity of 24 L and constructed of PVC material, its function is to prevent clogging by coarse materials;
- Septic Tank: constructed according to NBR 7.229/93 (ABNT, 1993) of volume 5.0 m^3 (1.723 m in diameter and 2.57 m in height), with a hydraulic retention time of 22 hours;
- *Wetlands*: 2.0 m^3 tanks, divided in two (1.64 m in diameter x 0.44 m in height for each tank), in which was cultivated macrophyte Papyrus (*Cyperus*);
- Ultraviolet system: made in stainless steel, brand SODRAMAR (2016)[1] model SUV 7. Consisting of a lamp, model TUV 4P S/E of 16W, tubular format, length of 32.8 cm and life of approximately 7000 hours (Philips[1]). The light is emitted in the UV-C band, which corresponds to about 260 nm.

The ultraviolet radiation dose of the lamp in question is 0.43 $mWscm^{-2}$, being calculated by the intensity of the flow ($mWcm^{-2}$) and multiplied by the time of exposure of the effluent to the UV (seconds) (Philips, 2006).

All units have appropriate seals so that there is no contamination in the water table.

2.2. Monitoring of Station

Sewage samples were collected between October 2016 and September 2017, from 09:30 am to 11:30 am, and were placed in sterilized containers and immediately sent to the Water and Soil Laboratory of the Department of Natural Resources and Environmental Protection (DRNPA/CCA/UFSCar).

Wastewater was monitoring was carried out according to the methodology indicated by the Standard Methods for the Examination of Water and Wastewater (APHA, 2012), in triplicate, corresponding to following parameters:

- Biweekly analyses: pH, dissolved oxygen (DO), turbidity and electrical conductivity (EC);
- Monthly analyses: total phosphorus (TP), total nitrogen (TN), calcium (Ca), magnesium (Mg), potassium (K), sodium (Na), total coliforms (TC), *Escherichia coli* and Sodium Adsorption Ratio (SAR).

For bacteriological analysis, the enzymatic method Colilert[1] was used according to IDEXX (2016).

Sodium Adsorption Ratio (SAR) is calculated by sodium (Na), calcium (Ca) and magnesium (Mg) according to Equation 1 (Lesch and Suarez, 2009):

$$\mathrm{SAR} = \frac{\mathrm{Na}}{\sqrt{\mathrm{Ca+Mg}}} \tag{1}$$

On what:

SAR = Sodium Adsorption Ratio $(\mathrm{mmol_c\,L^{-1}})^{1/2}$;

Na = concentration of sodium ($\mathrm{mmol_cL^{-1}}$);

Ca = concentration of calcium ($\mathrm{mmol_cL^{-1}}$);

Mg = concentration of magnesium ($\mathrm{mmol_cL^{-1}}$).

The efficiency of each parameter was calculated from a balance between the input and output means of each treatment unit (Equation 2) (Von Sperling, 2005):

$$E = \frac{Ce - Cs}{Ce} x100 \quad (2)$$

On what:

E = removal efficiency (%);

Ce = concentration of the parameter in the raw wastewater (input);

Cs = concentration of the parameter in the treated wastewater (output).

[1]Trademark references do not constitute an endorsement by the authors.

3. RESULTS AND DISCUSSION

Table 1 presents the results of wastewater characterization from 24 samples during the one-year monitoring.

Table 1. Average values of raw wastewater (input) and treated wastewater (output) of monitoring parameters and removal efficiency.

Parameters	Input	Output	Overall efficiency (%)
pH	6.8	6.4	---
Turbidity (NTU)	87.3	2.7	96.9
EC (µS cm^{-1})	639.5	444	30.6
DO (mg L^{-1})	3.3	6.5	98.5*
Na (mg L^{-1})	8.2	10.3	26.7*
K (mg L^{-1})	49.4	15.7	68.2
Ca (mg L^{-1})	13.5	16.6	22.9*
TN (mg L^{-1})	23.4	10.7	54.1
TP (mg L^{-1})	5.6	3.6	36.1
Mg (mg L^{-1})	10.3	8.8	14.6
TOC (mg L^{-1})	60	23.6	60.6
TC (MPN $100mL^{-1}$)	$4.7x10^7$	$8.8x10^3$	99.98
Escherichia coli (MPN $100mL^{-1}$)	$2.6x10^7$	$6.1x10^2$	>99.99

EC = electrical conductivity; DO = dissolved oxygen; Na = sodium; Ca = calcium; TN = total nitrogen; TP = total phosphorus; K = potassium; TOC = total organic carbon; Mg = magnesium; TC = total coliforms in Most Probable Number (MPN).
* percentage increase of the parameter in the units of the Station.

Reuse in agriculture requires wastewaters to have a pH that does not negatively influence the development of agricultural crops. Martínez *et al.* (2015) describe that the pH for reuse in agriculture should be between 5 and 6.5, to facilitate the absorption of nutrients by plants.

In this sense, the crude wastewater presented averages of 6.8 at the entrance and 6.4 at the exit. Colares and Sandri (2013) also observed a decrease in pH in their cultivated bed surveys, concluding that the bacteria produce organic acids due to the anaerobic degradation of the organic matter, leading to discrete acidification of the wastewater.

The station showed a reduction of 96.9% of turbidity, with input and output averages of 87.3 and 2.7 NTU, respectively. At the exit of the septic tank, the turbidity presented an index of 80.9% and, after *Wetlands*, reached 83%. Colares and Sandri (2013) found lower values in relation to the septic tank of 37.8%; for the flooded systems, the averages found were close to those observed in the Station, with rates from 66.9 to 82.5%, which demonstrates excellent removal of suspended solids from the Pilot Station septic tank and *Wetlands*.

Electric Conductivity had a reduction efficiency of 30.6%, from 639.5 µS cm^{-1} to 444 µS cm^{-1}, and the Na, Ca and K parameters showed variations in their concentrations. Souza *et al.* (2015) found an increase in EC of 36.3% during the wastewaters treatment and stated that the main reason would be to raise the same parameters mentioned above in units containing brittle.

The content of DO had a mean input of 3.3 mg L^{-1} and the output wit 6.5 mg L^{-1}, totaling an increase in oxygenation of wastewater of 98.5%. In the *Wetlands*, there is an occurrence of photosynthesis, leading to an increase of dissolved oxygen at the outlet of the flooded system.

Sodium showed an increase of 26.7% in the final wastewater, the highest increase was observed at the exit of the septic tank, with rates of 15.8%. The final wastewater of the STS has 0.4 mmol L^{-1} of sodium and, according to Ayers and Westcot (1999), does not present risk in the case of surface irrigation to the soil and the culture.

The overall efficiency of removal of K of the STS Pilot, since the entry, with 49.4 mg L^{-1} until the exit with 15.7 mg L^{-1}, was 68.2%. The limit established for irrigation water is up to 2 mg L^{-1} (Ayers e Westcot, 1999). Therefore, the value of the final wastewater of the STS presents restrictions on K, since they can present problems of loss of water to the plants, reducing transpiration, damaging growth and the absorption of other essential nutrients to the plant, such as calcium, magnesium, boron, zinc, manganese, and ammonium (Fia *et al.*, 2015).

Calcium had an increase of 22.9% from input to output (0.41 mmol L^{-1}) and its greatest contribution to this elevation was after the wastewater entered the system of *Wetlands.* According to Ayers and Westcot (1999), the threshold value found in irrigation water would be 10 mmol L^{-1}.

Results of NT demonstrated a contribution of 30.6% after the septic tank; however, the wastewater entering the *Wetlands* had a reduction efficiency of 74.6%. In the final wastewater, the concentration of NT detected was 10.7 mg L^{-1}. The total efficiency of removal was 54.1%. According to the recommended literature, the appropriate range for irrigation with wastewater would be 10 mg L^{-1} of total nitrogen (Ayers and Westcot, 1999).

Total phosphorus showed an average input of 5.6 mg L^{-1}. The Pilot STS presented total removal efficiency of 36.1% TP. The highest reduction rate recorded in the Pilot Station was in the *Wetlands*, with 82.7%.

However, after the incidence of UV radiation on the wastewater, TP increased the rate from 2.4 to 3.6 mg L^{-1}, representing 50%. This elevation in TP contents may be associated with phosphate accumulating organisms present in wastewater under anaerobic and aerobic conditions.

These microorganisms submitted to ultraviolet radiation showed a breakdown of genetic material, where phosphorus would be absorbed intracellularly. After undergoing UV cell lysis, the nutrient becomes available and detectable in the final analysis of the effluent. By classification of Ayers and Westcot (1999), the maximum found in irrigation water for TP would be 0-2 mg L^{-1}.

A concentration of Mg had a total removal efficiency of 14.6%, the final wastewater was observed with 8.8 mg L^{-1}. The recommendation for application of water in irrigation is not to exceed the margin of 100 mg L^{-1} (Ayers and Westcot, 1999).

The overall efficiency of removal of TOC from input to output was 60.6%. Only at the exit of the septic tank was the removal 59.8%, due to the biodegradation of the organic matter. After this process, the wastewater practically remained with the same average until the exit of the pilot STS.

Total coliforms reached a full efficiency of removal, that is to say, 99.98%, from $4.7x10^7$ to $8.8x10^3$ MPN per 100 mL in the crude wastewater. Moreover, removal was greater than 99.99% for *E. coli* from $2.6x10^7$ to $6.1x10^2$ MPN per 100 mL in the crude wastewater, which demonstrates the high disinfection potential of ultraviolet radiation, reducing more than 4 log-cycles from an initial load of TC and 5 log-cycles from an initial load of *E. coli*, suggesting microbiological safety.

The NBR 13.969/97 allows the application of water for reuse to include maximum values of 5.000 NMP 100 mL of *E. coli*. However, the World Health Organization (WHO, 2006) recommends that the values for *E. coli* do not exceed 10^3 in 100 mL for unrestricted irrigation, that is, crops that can be ingested raw.

As with the efficiency of the UV treatment unit, removals were 96.6 and 91% for TC and *E. coli*, respectively, reducing 1log-cycle with a radiation dose of 0.43 $mW.s.cm^{-2}$.

For this result, the difference between the wastewater values of the *Wetlands* outlet and the UV outlet was analyzed (Table 2).

Table 2. Monitoring of total coliforms (TC) and *E. coli* in the input and output of the treatment unit by UV radiation.

	Wetlands *output*	*UV output*
TC	$8.2x10^4$ MPN 100 mL^{-1}	*$8.8x10^3$ MPN 100 mL^{-1}*
E. coli	*$6.8x10^3$ MPN 100 mL^{-1}*	*$6.1x10^2$ MPN 100 mL^{-1}*

Bilotta and Daniel (2012) tested the effect of effective UV doses (123.0 and 247.0 $mWscm^{-2}$) on effluent from secondary treatment with exposure times of 60/120 seconds and noted the inactivation of 1.6 to 5.2 log-cycles of *E. coli*.

Souza *et al.* (2012) in one of their UV assays observed that 317.1 $mWscm^{-2}$ were required to inactivate 3.7 and 2.0 log-cycles of *E. coli* and CT, respectively. However, a dose of 42.28 $mWscm^{-2}$ was able to disinfect approximately 5 log of the same microorganisms.

Therefore, it is understood that the effluent quality interferes directly with the dose applied by UV radiation.

Sodium Adsorption Ratio (SAR) of the final wastewater presented an average of 0.5 $(mmol_cL^{-1})^{1/2}$, where the minimum observed was 0.2 $(mmol_cL^{-1})^{1/2}$ and the maximum 2.2 $(mmol_cL^{-1})^{1/2}$. This discrepancy in SAR may be associated with a disproportionate increase in Na, Ca and Mg. In order to avoid impacts by the application of the wastewater, the classification according to Ayers and Westcot (1999) for SAR should be between 0-15 $(mmol_cL^{-1})^{1/2}$.

The septic tank, *Wetlands* and UV showed distinct behaviors, in which the parameters suffered inflow or removal efficiency (Table 3).

Table 3. Removal efficiency of parameters for treatment units.

	Removal efficiency %		
	Septic Tank	*Wetlands*	UV
Turbidity	80.9	83	4.3
EC	NR	38.5	NR
DO	NR	NR	NR
Na	NR	NR	NR
K	11.8	71.4	NR
Ca	NR	NR	9.9
TN	NR	74.6	NR
TP	NR	82.7	NR
Mg	14.3	NR	3.7
TOC	59.8	NR	2.19
TC	96.3	95.2	89.3
E. coli	99.3	96.1	91

NR: not removed.

The septic tank, considered a unit of primary treatment, was responsible for the largest removals of TOC, Mg, TC and *E. coli*.

The first two parameters are associated with the degradation and stabilization of organic matter by the anaerobic bacteria present in this treatment phase, and the release of methane gas. For the bacteriological indicators, the average of efficient removal may range from 60 to 90% (Von Sperling, 2005).

In the *Wetlands*, due to filtration and the polishing of wastewater, there was greater removal turbidity and a decreased EC, due to the consumption of salts by the macrophytes (Santos *et al.*, 2016).

The nutrients NT (74.6%), PT (82.7%) and K (71.4%), the main ones for the development of agricultural crops, demonstrated the removal efficiency of the percentages found in the literature (Fia *et al.*, 2017).

According to the presented results, the viability of the agricultural use of the treated wastewater of the Pilot STS is verified, mainly due to the contribution of nutrients. Therefore, this proposal is in line with sustainable agricultural production, since it represents an economy in terms of nutrients/water resources, combining agriculture with the environment.

4. CONCLUSIONS

In experimental conditions, it is possible to state that the final wastewater from the pilot scale Sewage Treatment Station has sanitary and agricultural viability for irrigation application.

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