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Influence of Cellulose on the Anoxic Treatment of Domestic Wastewater in Septic Tanks: Statistical Analysis of the Chemical and Physico-Chemical Parameters

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Abstract: Cellulose is a very common polymer in domestic wastewater (WW), representing a not negligible part of the organic substance contained in sewage. To date, many studies have highlighted the feasibility of reusing this compound in several ways (e.g., building sector, wastewater treatment, energy production, etc.) after its separation from domestic WW. However, studies about the impact of the absence of cellulose on the chemical and physico-chemical parameters of a biological process are still lacking. In this work, two pilot-scale plants were used to simulate an anoxic treatment of WW in septic tanks, with and without cellulose (CWW and NCWW, respectively), for three months. The results of the monitoring highlighted that T, pH, and electrical conductivity (EC) remained almost constants, in both cases. The Spearman correlation coefficients (SCC) for turbidity (TUR), total suspended solids (TSS), and color (COL) indicated a higher removal in the case of CWW (65%, 66%, and 56%, respectively). Organic substance and nitrogen forms showed a similar behavior with and without cellulose, but in the case of CWW, N-NH_3 was highly negatively correlated with TUR (SCC: −0.54), TSS (−0.49), and COL (−0.39). A biological denitrification process was highlighted in both cases. Despite these differences, when statistically analyzing the trends of the chemical and physico-chemical parameters for CWW and NCWW, a significant difference due to the absence of cellulose was excluded. These results will be useful to the scientific community, as they exclude that the operational parameters of anoxic treatments and the effectiveness on pollutants removal can be affected in the case of preliminary cellulose separation from domestic WW for recovery/reuse purposes.

Keywords: domestic wastewater; toilet paper; cellulose; anoxic degradation; septic tank

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1. Introduction

Domestic wastewater (WW) can contain several substances including organic matter, ammonia, phosphorus, and other compounds such as cellulose and heavy metals released in the sewer system by anthropic activities [1–4].

Cellulose is the most widespread polymer on earth and can be found in nature in the chemical forms of monomers and polymers [5]. In domestic WW, cellulose mainly originates from toilet paper and reaches the wastewater treatment plant (WWTP) in fibers, generally without change in their composition and structure, during transport in the sewer system [6–8]. Cellulose also represents up to the 50% of the insoluble substance in urban WW and is the largest insoluble component affecting the chemical oxygen demand (COD) (up to 25–30%) [6,9].

Cellulose can be treated in different ways. In some countries, it is flushed away and is part of the composite WW, while in countries where the sewers present clogging problems, toilet paper is collected separately and disposed of as solid waste [6]. In the countries of Western Europe, toilet paper ends up in sewers and reaches the WWTPs as an integral part of the influent being separated from water flux in primary settlers [10].

This because, generally, the simultaneous decomposition of cellulose as an insoluble component of WW together with other soluble organic substances is difficult, and its degradation in activated sludge and excess sludge, both in aerobic and in anaerobic conditions, is still under discussion [6,8]. Due to its structure, cellulose needs to be hydrolyzed, before a possible biological degradation. Therefore, aerobic processes in conventional WWTPs, such as conventional activated sludge, seem not able to significantly affect cellulose concentration [9]. Biological hydrolysis of cellulose occurs in anaerobic conditions and strongly depends on temperature and sludge retention time. For instance, the decomposition of cellulose by microbial hydrolysis during anaerobic digestion is slower than that of lipids and proteins. The anaerobic digestion of cellulose in conventional WWTPs can be potentially increased by using thermophilic conditions and maintaining an acidic environment, but due to the need of a large amount of energy and chemicals, this process is not economically sustainable [8]. Consequently, most cellulose pulp is precipitated or sieved in the primary treatment [8].

Therefore, in addition to proteins, carbohydrates, and other organic substances, a significant part of the organic matter in primary sludge comes from cellulose [6]. Several studies highlighted the possible separation of cellulose from primary sludge with fine screens (<350 μm) to obtain, for instance, biofuels, due to its high energetic value [9,11]. Cellulose could be potentially reuse in the construction sector [12], in the production of new paper materials [13] and of nanoscale-based composites after dimension reduction [4], as an alternative adsorbent in WW treatment [14], or as a biofuel, given its high energetic value [15,16].

Given the average concentration of cellulose in urban WW can reach 200 mg L^{-1}, its large recovery/reuse could potentially involve a high amount of material [8]. Some authors also suggested that the removal/separation and the subsequent energy recovery from cellulose can lead to an overall energy optimization and more cost-efficient WWTPs [9].

Despite many studies evaluating the possibility of the separation and recovery of cellulose from WW, the number of works which focused on the impact of WW treatments is still limited. Moreover, most of them studied the influence of cellulose on WW aerobic treatment in WWTPs, but not much information is available about the effect of the presence/absence of cellulose on the anoxic treatment of domestic WW at a low scale.

Septic tanks represent one of the most spread solutions for onsite primary treatment, where a direct WW collection in the sewage system is not possible (e.g., in rural regions) [17,18]. They are designed as one- or double-compartment reactors with usually three zones in which it is possible to detect: (i) a scum layer on the top, (ii) the WW, and (iii) a bottom layer constituted mainly of sludge and deposited materials [19].

Despite some authors pointing out the absence of robust data about the microbial communities and their activity in septic tanks [20], others confirmed biological degradation in septic tanks occurs, helping the reduction of the content of organic pollutants and suspended solids by more than 50%, mainly depending on the operational conditions [21,22].

Considering that the separation of cellulose from WW is gaining interest and will be presumably more spread in future [23], the enhancement of the knowledge about the impact of the removal of this compound from WW on the treatment processes represents a priority. This work aimed to evaluate the influence of the absence of cellulose in domestic WW on chemical and physico-chemical parameters during the anoxic treatment of WW in a septic tank in order to obtain data that are currently lacking in the literature. Two synthetic types of WW, with and without cellulose, were prepared to simulate domestic WW and treated in anoxic conditions in two pilot plants. The septic tanks were monitored for three months, and the results were analyzed to find possible patterns between parameters and statistical differences between the trends.

The results will be useful to the scientific community to evaluate the possible impact of cellulose separation from WW for recovery/reuse purposes on the operation parameters of anoxic treatments and on pollutant degradation.

2. Materials and Methods

2.1. Preparation of Synthetic Wastewater

Two synthetic types of WW were prepared to simulate domestic wastewater, one with cellulose (CWW), and the other without cellulose (NCWW). To obtain WW best representing domestic wastewater, data about the proportion and amounts of drinking water consumption for domestic use stated by the Prague Waterworks and Sewerage were used [24]. Considering that data from Belgrade were not available when the tests were performed, data from Prague were considered due to their similarity with those from Belgrade.

The average daily consumption of drinking water as a function of domestic activities is presented in Table S1. In that case, it was assumed that the total amount of drinking water will be released into the sewer system (consumption for watering were not considered). These ratios were used to produce a synthetic WW (both for CWW and NCWW) with similar characteristics to those of the real domestic one.

Toilet WW (with feces and urine) was mixed with WW of other sources. Contributions from personal hygiene and showering were simulated using common shampoo and shower gel. The contribution from handwashing, laundry, and cleaning were simulated by adding commercial hand soap, washing powder, and detergents. WW due to food preparation and dish washing was simulated by adding water with a common dish detergent and leftover food in the ratio of 19:1. Toothpaste and commercial drugs were also added to better simulate the real conditions.

Despite investigating the interaction of pharmaceutical products with other compounds was not in the aim of the work, some drugs which are commonly consumed by the population were added to obtain a representative sample of domestic WW. The pharmaceutical compounds and their amounts added were defined according to estimations of the usual consumption of the most widespread medicines in daily use. The details are reported in Table S2.

The literature suggests that toilet paper is the primary contributor to WW cellulose, while kitchen waste contributes in a smaller amount [25]. Therefore, assuming a yearly production of 15 kg y^{-1} of toilet paper [6] and based on the used volumes, 137.6 mg L^{-1} of toilet paper was added in CWW together with two sheets of kitchen paper and handkerchiefs (90.9 mg L^{-1}).

The main characteristics of the untreated CWW and NCWW are reported in Table 1. The two types of WW only differed for the addiction of cellulose-made materials.

Table 1. Characteristics of untreated wastewater with and without cellulose (CWW and NCWW, respectively). COD: chemical oxygen demand; TSS: total suspended solids; COL: color; EC: electrical conductivity; TUR: turbidity.

Parameter	CWW	NCWW
COD [mg L^{-1}]	2827	2605
N-NH_3 [mg L^{-1}]	34.8	33.2
N-NO_3^- [mg L^{-1}]	33	7
N-NO_2^- [mg L^{-1}]	0.49	0.16
TUR [NTU]	941	307
TSS [mg L^{-1}]	842	501
COL [° Pt-Co]	8800	8900
pH [-]	7.9	8.1
EC [µS cm^{-1}]	2300	2090

2.2. Experimental Set-Up

The tests were carried out in Belgrade, Serbia. Two pilot plants, consisting of two plastic tanks (volume: 25 L), were located in the yard of the laboratory of the Faculty of Civil Engineering of the University of Belgrade, in an open-space position.

The tests were carried out for three months to be sure that the complete decomposition of cellulose was reached [26]. The pilot plants were thermally insulated to avoid the influence of the external temperature and to maintain the temperature required for the development of microorganisms simulating the conditions of a buried septic tank.

Above the mass of WW, in each pilot plant, a layer of 100 mm of air was granted to better simulate septic tank conditions. Ventilation of the plants was provided through a plastic tube with a cross section of 5 mm.

The pilot plants operated in batch mode, with samples taken weekly for three months. Before each sampling was performed, the whole content of the tank was stirred to homogenize the WW and prevent the deposition of material.

2.3. Analytical Methods

During the experiments, dissolved oxygen was continuously monitored with the multiparameter device HQ40d multi (Hach Company, Loveland, CO, USA) to check the dissolved oxygen concentration (0.1–0.5 mg L^{-1}). The same equipment was also used to evaluate temperature (T) and electrical conductivity (EC). The pH was monitored through a Metrohm 827 pH lab device (Metrohm AG, Herisau, Switzerland), while turbidity (TUR) was quantified using the Turbidimeter HACH 2100Q (Hach Company, Loveland, CO, USA).

N-NH_3, N-NO_3^-, N-NO_2^- were analyzed using kits purchased from Hach Company based on Nessler and cadmium reduction and diazotization principles, respectively. The methods 8038 [27], 8171 [28], and 8507 [29] were followed for the analysis of N-NH_3, N-NO_3^-, N-NO_2^-, respectively. Color (COL) and total suspended solids (TSS) were measured according to Methods 8025 [30] and 8006 [31]. For spectrophotometric measures, the spectrophotometer HACH DR-2800 was used (Hach Company, Loveland, CO, USA). N-NO_X was calculated as the sum of N-NO_3^- and N-NO_2^-.

The soluble chemical oxygen demand (COD) was analyzed with Hach kits (Hach Company, Loveland, CO, USA), after filtration (pore size, 0.45 µm), excluding a possible interference of chlorides.

All of these measurements and analyses were performed immediately after sampling.

2.4. Data Processing and Statistical Analysis

Firstly, correlations between the measured chemical and physico-chemical parameters were computed with both Pearson's and Spearman's rank correlation tests.

Moreover, to understand if the trends of the chemical and physico-chemical parameters for CWW and NCWW were statistically different, a coefficient of variation (CV) with respect to the average value of the same pollutant monitored in the previous three weeks was calculated. One-way analysis of variance (ANOVA) was used to examine the differences between CWW and NCWW for each compound. The analyses were conducted using Excel software (Microsoft Corporation, Redmond, WA, USA). A significance level of <0.05 was set.

3. Results and Discussion

3.1. Monitoring of the Chemical and Physico-Chemical Parameters

T, pH, EC, TUR, TSS, COL, COD, N-NH_3, and N-NO_X, for both types of WW, were monitored along the entire duration of the experimental phase, and the results are reported in Figure 1.

The temperature was slightly higher for CWW with respect to NCWW (21.8 $\pm$ 0.5 °C vs. 21.4 $\pm$ 0.5 °C, respectively) (Table S3). Because of its abundant organic substance content, cellulose is a source of carbon and energy for a wide range of microorganisms [32]. During the biodegradation process, the biota could release a certain amount of energy, generating heat and producing a slightly increase in the temperature [33].

The monitoring of operational parameters such as the temperature represents a very import operation for biological processes as that which occurs in septic tanks, influencing their effectiveness. According to the equation of Van't Hoff–Arrhenius [34] (Equation (S1)) and assuming the coefficient of reaction rate at 20 °C equal to 1.104 d^{-1} and the coefficient of temperature activity equal to 1.06 [35], the average coefficient of reaction rate was almost 2% higher for CWW than for NCWW during the experimental procedure.

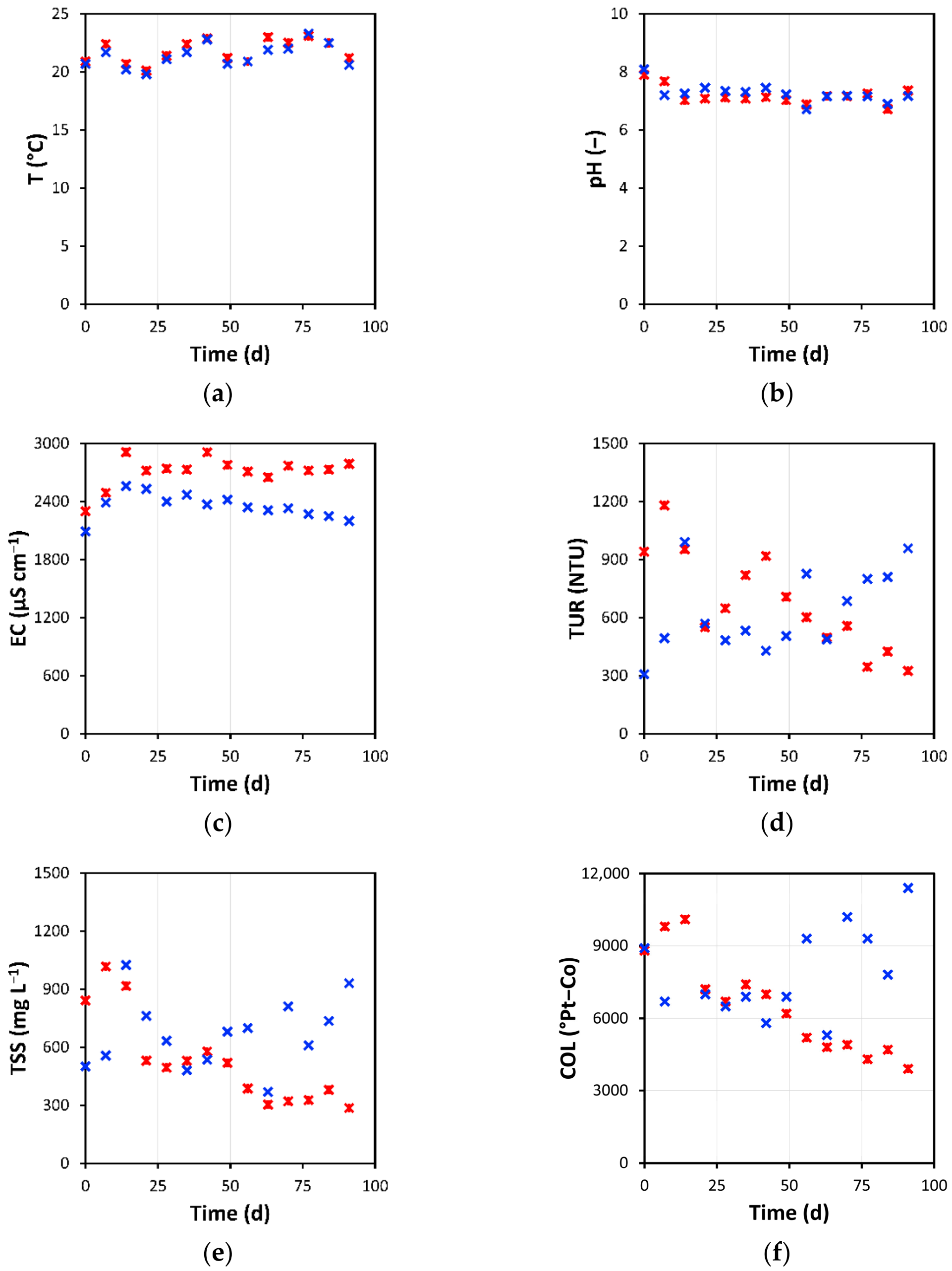

Figure 1. *Cont.*

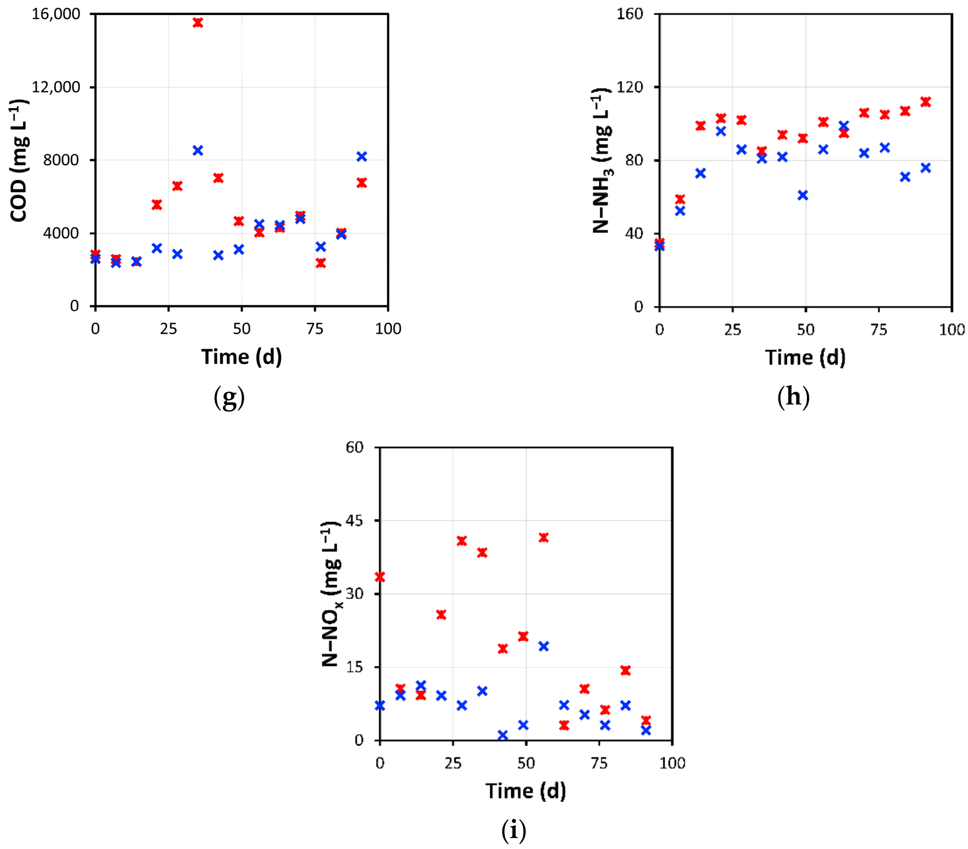

Figure 1. Trend of (**a**) T, (**b**) pH, (**c**) EC, (**d**) TUR, (**e**) TSS, (**f**) COL, (**g**) COD, (**h**) N-NH_3, and (**i**) N-NO_X in the tests of CWW (red data) and NCWW (blue data).

Cellulose did not affect the pH value, being an inorganic matrix. The measured pH values for both samples were approximately the same (7.2 $\pm$ 0.2 and 7.3 $\pm$ 0.2 for CWW and NCWW, respectively). The results showed, as expected, that the pH value was constant over time, for both analyzed samples. The slight decrease of pH after two weeks could be the result of the production of acidic metabolites due to the degradation of organic matter in the lack of dissolved oxygen [36].

The EC for CWW was constantly higher than for NCWW (2710.7 $\pm$ 78.8 µS cm^{-1} vs. 2352.1 $\pm$ 64 µS cm^{-1}, respectively), on average, by almost 15%. During the tests, the value of EC was mostly constant, suggesting that the number of ions in both solutions did not change significantly because the EC is a linear function of the present concentration of ions [37]. The fact that cellulose is composed of glucose chains containing a hydroxyl -OH group explains the higher values of EC for CWW [38].

TUR showed similar results as COL and TSS. At the end of monitoring, TUR of CWW was almost three-times lower than that of NCWW (325 NTU vs. 958 NTU, respectively) with a 65% of removal, confirming previous findings which highlighted that cellulose in WW seemed to have a beneficial effect on water clarification and turbidity reduction [39]. In the initial WW, cellulose represented almost 36% of TSS in accordance with Akyol et al. [40], with initial TSS higher for CWW with respect to NCWW (842 mg L^{-1} vs. 501 mg L^{-1}, respectively), but at the end of the experimental phase, TSS in CWW decreased by almost 66%. This result agrees with previous studies which highlighted a reduction of TSS in a septic tank, ranging from 30 to 80% [41]. On the contrary, removing cellulose from WW seemed to reduce the removal of TSS at the end of the treatment. In addition, COL underwent a higher removal in the case of CWW (56%).

The soluble COD increased after almost one month due to the dissolution of particulate COD [42] and tended to decrease in the end of the experimental phase.

The initial N-NH_3 concentration was not affected by the removal of cellulose, being urine the main source of N-NH_3 in WW [43]. Moreover, the initial value (almost 30 mg L^{-1}) was in accordance with the typical characteristics of domestic WW [44]. A significant increase in N-NH_3 concentration was found in the initial weeks for both types of WW (up to 103 mg L^{-1} and 96 mg L^{-1} for CWW and NCWW, respectively). This could be due to the transformation of organic nitrogen into ammonia, which can take place also in the case of a low concentration of oxygen [45].

Despite the initial N-NO_x concentration being almost five times higher in CWW than in NCWW (33.5 mg L^{-1} vs. 7.2 mg L^{-1} for CWW and NCWW, respectively), N-NO_x were quite completely removed from both types of WW (88% and 71% for CWW and NCWW, respectively), considering that anoxic conditions stimulate the denitrification process [46].

3.2. Correlation Analysis

To determine possible correlation patterns between each parameter and cross-correlations among the results obtained with different types of WW, Pearson moment and Spearman rank correlation coefficients were calculated. The Pearson correlation coefficient (PCC) indicate a possible linear relation between two variables, while the Spearman's correlation coefficient (SCC) measures the degree of non-parametric relationship between two variables. For both coefficients, the value ranges between −1 and +1, with a value close to 0 meaning that the two examined variables are not correlated.

About the Pearson correlation coefficient, some CWW parameters seemed to show a linear dependence on others (Figure 2a). For instance, COL showed a highly positive PCC for the relationship with TUR and TSS (0.91 and 0.97, respectively). Similar results were obtained also for NCWW, with the PCC for color and TUR and TSS higher than 0.75. This could mean that the chromophore substances in WW were mainly in particulate forms and of colloidal nature. Despite COL, TUR, and TSS not being normally distributed, and the reliability of PCC being limited, the results were confirmed also with the analysis of the SCC, obtaining similar outcomes (Figure 2b). When evaluating the PCC and SCC for the different types of WW, no evident relation was visible, which did not define if cellulose influences or not the trends of the examined parameters.

The pH showed a strongly negative linear relation to the EC in the case of CWW (−0.74) and a lower correlation in the case of NCWW (−0.20). This difference could be due to the different compounds contained in CWW. Generally, the EC is related to the number of ions in WW, which can be pH-determining ions or not [37]. As reported in Section 3.1, cellulose is composed of glucose chains containing a hydroxyl (-OH) group [38].

Studying the correlation between parameters for the different types of WW, T in the two simulated conditions showed high PCC and SCC (0.94), while also pH and EC exhibited a positive correlation, as indicated by both coefficients, with TUR, TSS, and COL. These results suggest possible similar trends for these pollutants, considering they reflect the results obtained studying the correlation of variables for each type of WW.

The COD seemed to be slightly negatively correlated with pH during the anoxic treatment of both types of WW, while N-NH_3 showed a more highly negative correlation (as measured by the SCC) with TUR (−0.54), TSS (−0.49), and COL (−0.39) in the case of CWW. The higher initial values of these parameters for this WW could have partially influenced the ammonification process.

A not very strong correlation for N-NO_X with other parameters was found.

		CWW									NCWW								
		T	pH*	EC*	TUR	TSS	COL	COD*	N-NH_3*	N-NO_X	T	pH*	EC*	TUR	TSS	COL	COD*	N-NH_3*	N-NO_X
CWW	T	1.00																	
	*pH	−0.02	1.00																
	*EC	0.06	−0.74	1.00															
	TUR	−0.09	0.44	−0.28	1.00														
	TSS	−0.28	0.51	−0.36	0.91	1.00													
	COL	−0.33	0.41	−0.27	0.91	0.97	1.00												
	*COD	0.12	−0.21	0.25	0.01	−0.22	−0.06	1.00											
	*N-NH_3	0.07	−0.79	0.83	−0.72	−0.71	−0.65	0.12	1.00										
	N-NO_X	−0.41	−0.09	−0.20	0.24	0.12	0.23	0.42	−0.25	1.00									
NCWW	T	0.94	−0.09	0.08	−0.16	−0.31	−0.38	0.03	0.12	−0.31	1.00								
	*pH	−0.22	0.70	−0.48	0.43	0.48	0.51	0.04	−0.68	0.19	−0.23	1.00							
	*EC	−0.24	−0.46	0.55	0.30	0.26	0.42	0.26	0.31	0.13	−0.31	−0.20	1.00						
	TUR	−0.14	−0.45	0.52	−0.46	−0.28	−0.32	−0.19	0.65	−0.38	−0.07	−0.63	0.10	1.00					
	TSS	−0.52	−0.30	0.50	−0.21	0.00	−0.02	−0.23	0.50	−0.24	−0.45	−0.27	0.24	0.79	1.00				
	COL	−0.37	0.03	0.20	−0.14	0.06	0.01	−0.28	0.20	−0.26	−0.30	−0.10	−0.09	0.77	0.81	1.00			
	*COD	0.11	−0.15	0.18	−0.39	−0.50	−0.45	0.72	0.29	0.02	0.00	−0.25	−0.12	0.29	0.06	0.15	1.00		
	*N-NH_3	0.19	−0.63	0.62	−0.57	−0.66	−0.52	0.27	0.80	−0.10	0.17	−0.50	0.41	0.28	0.05	−0.15	0.26	1.00	
	N-NO_X	−0.40	−0.22	−0.17	0.21	0.21	0.27	−0.02	−0.10	0.50	−0.38	−0.34	0.29	0.19	0.06	0.14	−0.01	0.08	1.00

(**a**)

		CWW									NCWW								
		T	pH*	EC*	TUR	TSS	COL	COD*	N-NH_3*	N-NO_X	T	pH*	EC*	TUR	TSS	COL	COD*	N-NH_3*	N-NO_X
CWW	T	1.00																	
	*pH	0.25	1.00																
	*EC	−0.02	−0.35	1.00															
	TUR	−0.30	0.05	−0.02	1.00														
	TSS	−0.43	−0.01	−0.08	0.89	1.00													
	COL	−0.49	0.00	−0.09	0.92	0.94	1.00												
	*COD	0.00	−0.09	0.41	−0.11	−0.19	−0.09	1.00											
	*N-NH_3	0.12	−0.21	0.34	−0.82	−0.71	−0.73	0.07	1.00										
	N-NO_X	−0.44	−0.38	−0.17	0.37	0.39	0.40	0.30	−0.34	1.00									
NCWW	T	0.94	0.12	−0.07	−0.19	−0.29	−0.39	−0.06	0.09	−0.22	1.00								
	*pH	−0.37	0.23	0.13	0.57	0.66	0.69	0.34	−0.50	0.38	−0.35	1.00							
	*EC	−0.38	−0.48	0.32	0.48	0.53	0.61	0.20	−0.27	0.31	−0.37	0.38	1.00						
	TUR	−0.23	−0.43	0.32	−0.41	−0.33	−0.33	−0.24	0.64	−0.30	−0.22	−0.59	0.05	1.00					
	TSS	−0.47	−0.37	0.52	−0.26	−0.16	−0.16	−0.09	0.68	−0.17	−0.44	−0.20	0.15	0.77	1.00				
	COL	−0.38	−0.08	0.23	−0.21	−0.17	−0.16	−0.34	0.48	−0.20	−0.32	−0.26	−0.18	0.78	0.74	1.00			
	*COD	0.22	−0.17	0.06	−0.67	−0.78	−0.64	0.46	0.49	−0.06	0.16	−0.49	−0.25	0.39	0.08	0.21	1.00		
	*N-NH_3	0.26	−0.10	−0.06	−0.54	−0.49	−0.39	0.22	0.41	−0.09	0.19	−0.22	0.11	0.07	−0.05	−0.17	0.41	1.00	
	N-NO_X	−0.43	−0.42	−0.37	0.34	0.35	0.49	−0.24	−0.25	0.33	−0.33	−0.14	0.48	0.26	0.02	0.05	−0.02	0.05	1.00

(**b**)

Figure 2. (**a**) Pearson correlation coefficients (PCC) and (**b**) Spearman correlation coefficients (SCC). *: data normally distributed. Positive and negative coefficients are highlighted in green and red, respectively.

3.3. Statistical Analysis of the Trends

A statistical evaluation of the differences between the absolute values of parameters cannot be used to define if the trends were similar. To understand if there was a statistical difference (or not) between the trends of the chemical and physico-chemical parameters examined, a coefficient of variation (CV) with respect to the average value of the same pollutant in the previous three weeks was calculated.

The CVs summarized the behavior of the parameters for the duration of the tests, with T, pH, and EC exhibiting almost constant values, and TUR, TSS, COL, COD, N-NH_3, and N-NO_X showing a more variable trend. Details about the CVs calculated for each parameter are reported in Figure 3.

Temperature, pH, and EC showed on average lower variability for the entire duration of the tests, with CV equals to 0.01 ± 0.03, -0.01 ± 0.02, 0.01 ± 0.02 in the case of CWW, respectively, and 0.01 ± 0.03, -0.01 ± 0.02, -0.01 ± 0.02 in the case of NCWW, respectively (Figure 4).

On average, COD and N-NH_3 exhibited the higher increase (0.29 ± 0.49 and 0.09 ± 0.11 for CWW, 0.25 ± 0.40 and 0.07 ± 0.17 for NCWW, respectively).

The increase of soluble organic matter due to the dissolution of particulate COD in the first step of the process [42] explains the higher CV for COD in first weeks (Figure 3g) with respect to the other ones.

Anoxic conditions are not conducive to the removal of ammonia, and this agrees with the absence of a negative CV. The positive CV was mainly influenced by the value measured in the first weeks of the tests, in which a huge amount of N-NH_3 was found (Figure 3h) due to the ammonification process (Section 3.1). After the initial step, when all organic nitrogen was transformed into N-NH_3, the concentration remained almost equal (Figure 1h), with a CV of nearly zero.

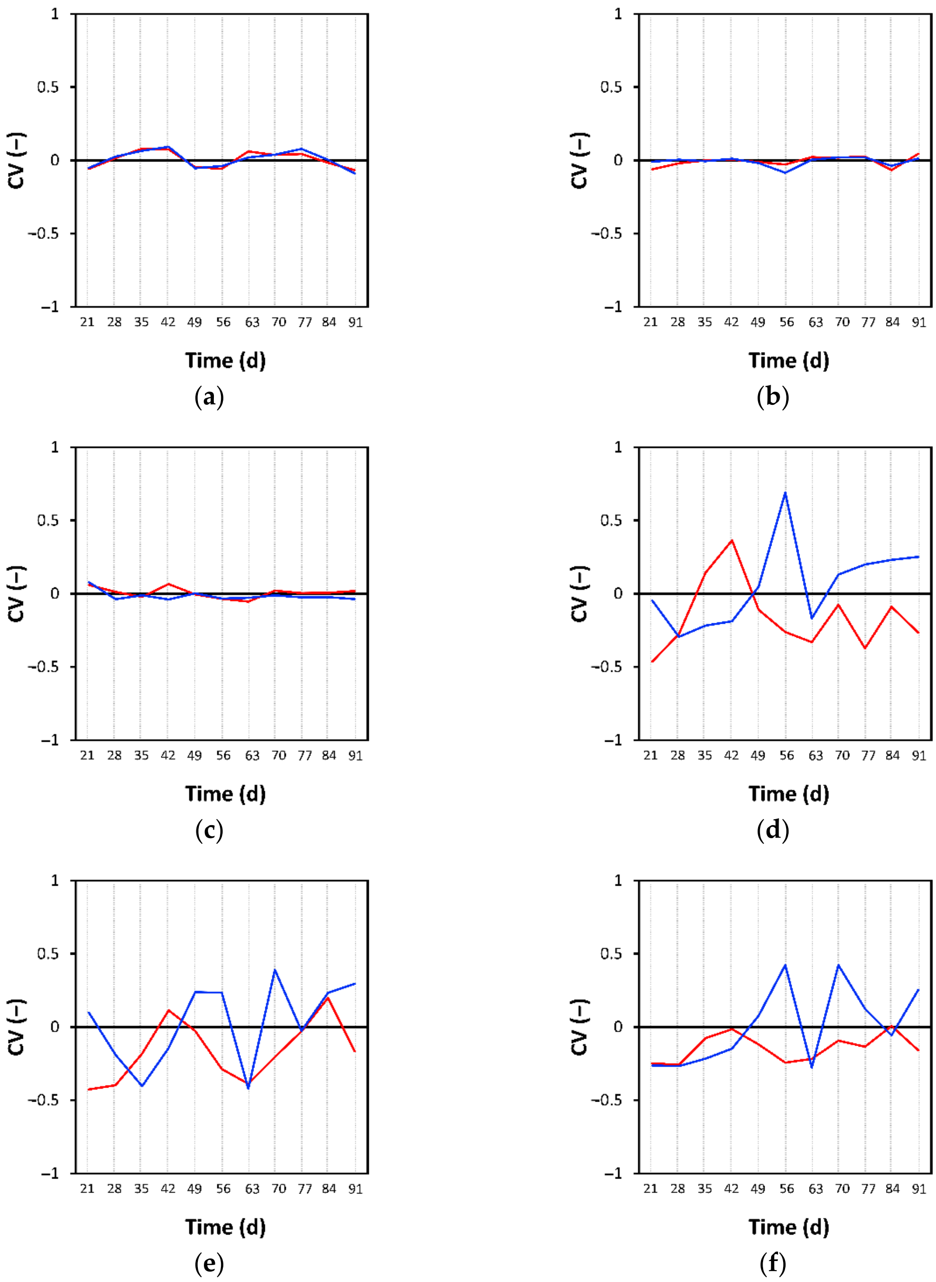

Figure 3. *Cont.*

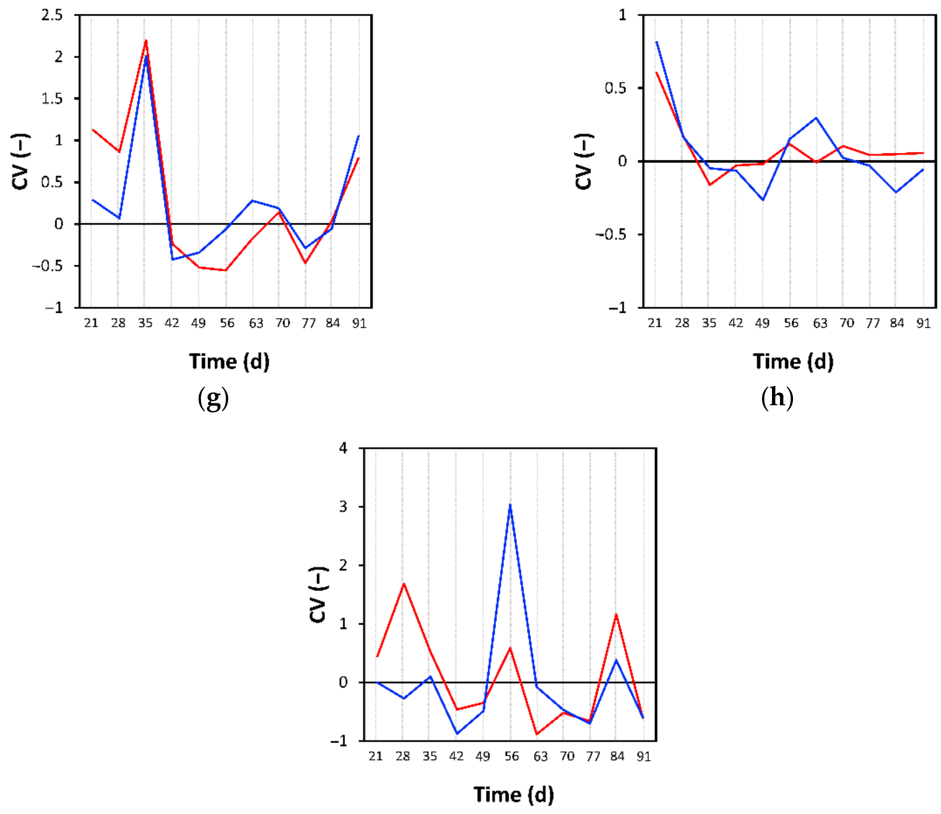

Figure 3. Coefficients of variation (CV) for (**a**) T, (**b**) pH, (**c**) EC, (**d**) TUR, (**e**) TSS, (**f**) COL, (**g**) COD, (**h**) N-NH_3, and (**i**) N-NO_X with respect to the to the average value of the same pollutant in the previous three weeks. CWW and NCWW are represented in red and blue, respectively.

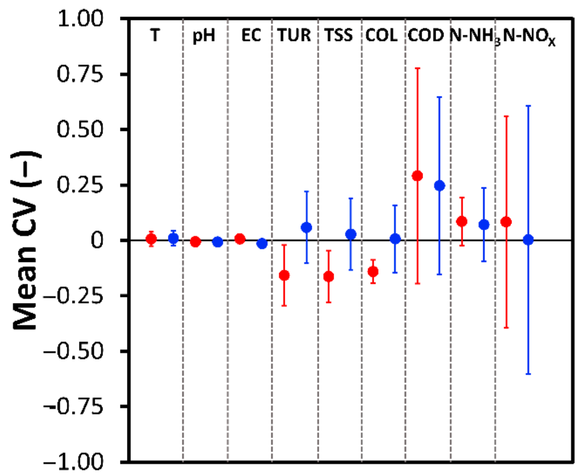

Figure 4. Mean coefficient of variations (CV). Bars represent the confidence interval at the 95th percentile. CWW and NCWW are represented in red and blue, respectively.

The absence of cellulose did not significantly affect the trend of N-NO_x, which was very variable in case of both positive and negative values, but with a CV, on average, of nearly to zero.

The CV of TUR, TSS, and COL showed, on average, similar trends, due to the high correlation between these parameters (Section 3.2). While for NCWW, CV close to zero were highlighted, in the case of CWW, the CV assumed negative values, on average (-0.16 ± 0.14, -0.16 ± 0.12, and -0.14 ± 0.05 for TUR, TSS, and COL, respectively).

Then, each set of data were statistically analyzed with one-way ANOVA to numerically define if cellulose in domestic WW can vary the trend of these parameters. The results suggested that no significant difference could be highlighted when adding cellulose in WW ($p \geq 0.05$).

Therefore, the presence of cellulose in WW seems to not determine a different trend of the evaluated parameters in the case of treatment in a septic tank. Given the interest about the possible recovery and reuse of cellulose from domestic WW is increasing, these results assume a strong importance, suggesting that the preliminary separation of cellulose from WW does not significantly affect the subsequent treatment in septic tanks.

This result is not obvious, given toilet paper, the main cellulosic product, accounts for 8–30% of total COD and 11–40% of TSS in domestic WW [9,47].

Previous studies already highlighted that the presence of cellulose fibers can impact the oxygen demand in aerobic biological processes and the amount of sludge produced and biogas released during the anaerobic digestion of sewage sludge [7]. However, to date no data about the possible impact on the anoxic treatment in septic tanks was available. In any case, to understand the potential effect of preliminary cellulose removal in the case of centralized and non-centralized domestic WW treatment systems, more research is needed to confirm the results also for full-scale systems.

4. Conclusions

In this work, two pilot-scale plants were used to simulate the anoxic treatment of WW in septic tanks, with and without cellulose. The results of the monitoring highlighted that parameters such as T, pH, and EC did not show a strong variation, with or without cellulose. High SCC correlation coefficients for TUR, TSS, and COL were highlighted. Moreover, a high removal of these pollutants in the presence of cellulose was pointed out (TUR: 65%; TSS: 66%; COL: 56%). Organic substance and nitrogen forms showed a similar behavior for both types of WW, but in the case of CWW, N-NH_3 was highly correlated with TUR, TSS, and COL (SCC: −0.54, −0.49, and −0.39, respectively). Due to the anoxic conditions, biological denitrification was found in both cases, with N-NOx quite completely removed from both types of WW (88% and 71% for CWW and NCWW, respectively). Despite these differences, when statistically analyzing the trends of the chemical and physico-chemical parameters for CWW and NCWW, a significant difference due to the absence of cellulose was excluded. Given the interest in the possible recovery of cellulose from domestic WW and its reuse is increasing, these results assume a strong importance, suggesting that the preliminary separation of that compound from WW does not badly affect the subsequent treatment in septic tanks. To fully understand the potential effect of preliminary cellulose removal for recovery/reuse in the case of conventional WWTPs, the authors suggest to continue this research, focusing also on the influence on the chemical and physico-chemical parameters in aerobic conditions. However, the results presented in this work will be useful to other scholars to exclude that the operational parameters during anoxic treatments of domestic WW and the effectiveness on pollutants removal can be affected by preliminary cellulose separation.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su15107990/s1, Equation (S1): Equation of Van't Hoff–Arrhenius [34]. Table S1: Average water consumption for domestic use. Data elaborated from [24]. Table S2: List of drugs in the wastewater samples and their mass fractions. *: These values referred to the dosage in each 20 L of WW. Table S3: Mean and confidence interval (C.I.) of the parameters monitored during the three months of tests on the pilot plants.

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Nomenclature

ANOVA: analysis of variance; COD: chemical oxygen demand; COL: color; CV: coefficient of variation; CWW: wastewater with cellulose; NCWW: wastewater without cellulose; EC: electrical conductivity; PCC: Pearson correlation coefficient; SCC: Spearman correlation coefficient; TSS: total suspended solids; TUR: turbidity; WW: wastewater; WWTP: wastewater treatment plant.

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