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Greywater Vertical Treatment and Possibility of Reuse in the Fields from Peri-Urban Area

Hanen Filali [1,2], Narcis Barsan [3,*], Georg Hörmann [4], Valentin Nedeff [3,5], Oana Irimia [3], Florin Nedeff [3] and Mohamed Hachicha [1]

1 National Research Institute of Rural Engineering, Water and Forests, University of Carthage, Ariana 2080, Tunisia
2 Faculty of Sciences of Bizerte, University of Carthage, Jarzouna, Bizerte 7021, Tunisia
3 Faculty of Engineering, Vasile Alexandri University of Bacau, 600115 Bacau, Romania
4 Department of Hydrology and Water Resources Management, Institute of Natural Resource Conservation, Kiel University, 24118 Kiel, Germany
5 Gheorghe Ionescu Sisesti, Academy of Agricultural and Forestry Sciences, 011464 Bucharest, Romania
* Correspondence: narcis.barsan@ub.ro

Abstract: This study highlighted the potential for greywater reuse in irrigation of olive trees. An experimental field was set up in a household of Soukra, located northwest of Tunis City, to test the performance of vertical greywater treatment. Treated greywater (TGW) was used for the irrigation of two olive tree varieties (Chétoui and Picholine) during five years. The results show high performance of the treatment, as reflected by the good quality of TGW. The chemical and biological parameters of this TGW are under the threshold values of the Tunisian Norms of Treated Wastewaters for agriculture use (NT106.03). The BOD_5 average decreased from 160.44 mg O_2/L for UGW (Untreated greywater) to 15.32 mg O_2/L for TGW. The COD average recorded a high reduction from 290.15 mg O_2/L for UGW to 49.58 mg O_2/L for TGW. The average removal rate was 90% for BOD_5 and 83% for COD, proving the high performance of the treatment. The average increases in height, diameter, and olive production are significantly high for the two varieties of olive trees irrigated with treated greywater (ITGW), compared to those not irrigated and under natural conditions. In this regard, the present study has shown promising potentials for the reuse of TGW in agriculture.

Keywords: greywater; treatment; use; olive trees; quality; Tunisia

Citation: Filali, H.; Barsan, N.; Hörmann, G.; Nedeff, V.; Irimia, O.; Nedeff, F.; Hachicha, M. Greywater Vertical Treatment and Possibility of Reuse in the Fields from Peri-Urban Area. *Agronomy* **2023**, *13*, 940. https://doi.org/10.3390/agronomy13030940

Academic Editors: Ping Li and Zulin Zhang

Received: 16 February 2023
Revised: 13 March 2023
Accepted: 20 March 2023
Published: 22 March 2023

1. Introduction

The use of treated wastewater is part of the national water strategy in many countries, as it contributes to the protection of the natural environment, the sustainability of agricultural production, the economy of conventional water, and the expansion of irrigated areas [1,2]. It also contributes to reducing the intrusion of seawaters in coastal areas by recharging groundwater [3]. On the other hand, it secures nutrients for the soil and plants, thereby reducing the total need for chemical fertilizers and increasing economic returns for farmers [1]. The water quality level for agricultural use has been the subject of regulations drawn up jointly between the different countries of the European Union [4]. This regulation aims to guarantee that reclaimed water is safe for agricultural irrigation, thereby ensuring a high level of protection for the environment and for human and animal health, promoting the circular economy, and supporting adaptation to climate change.

Wastewater comes with a large percentage of domestic/urban consumption in cities where treatment plants are located, and a small percentage from industrial areas [5]. Despite the amount of treated wastewater amounting to several million cubic meters [3], the use of treated wastewater remains weak [6] and the areas irrigated with treated water are very limited [7]. The reuse of treated wastewater in agriculture faces many problems, including some quality issues due to a lack of maintenance and an excess of treatment capacity [6,8].

In addition to this, the constituent and operational costs can be considered (in principal treated water transport) [8]. On the other hand, many treatment plants are located in depressions in the urban center where lands are usually affected by waterlogging and salinity [9]. In many cases, especially around the big cities, urban development has swept away many fertile agricultural plains [10].

The reuse of domestic wastewater in urban agriculture, known as greywater, is one of the solutions that contributes to alleviating the problems of wastewater treatment and the pressure on fertile lands around cities [11].

Greywater, domestic wastewater without toilet water (black water) [8], constitutes about 65 to 75% of the total domestic water and is relatively less polluted [6,8]. Treatment methods differ according the country and social and economic characteristics, which can be summarized as follows:

- Natural methods: based on sedimentation and filtration [12].
- Chemical methods: some chemicals are used for disinfection [13].
- Biological methods: in which vital activities and some disinfectant plants, such as reeds, are used [14,15].

As for the design of raw water treatment, two designs can be mentioned. The horizontal design refers to a process whereby the water passes from top to bottom through a sand filter of different sizes; it is then collected in a basin from which it is pumped to the irrigated trees [16]. The vertical design refers to a process whereby the water passes through a basin from the raw water source to the treated water bowl, which is then pumped to the irrigated trees [17].

Treated greywater contributes to preserving and providing drinking water by replacing irrigation with fresh water or flushing toilets with this type of water [18]. It also relieves pressure on treatment plants and provides the exploitation of agricultural fertilizers. Finally, it gives the beneficiary a material return that motivates them to stick to agriculture in urban and semi-urban areas that are under pressure from urban expansion [9,19].

In addition to these benefits, there are some risks that require precautionary measures [20]; this includes the possibility of high microbial content and chemical content within the water [21], which comes from the behavior of inhabitants and the materials used for household purposes [22,23]. Additionally, failure to treat this water as soon as possible may increase the risks, given the possibility of rotting water if it is stored for long periods.

The use of greywater is not innovative, as this type of water source has been valued since ancient times, especially in arid and semi-arid environments and during seasonal periods of drought. However, this use was not systematic, without treatment and without taking the slightest precautions, even at the level of irrigated crops such as vegetables. A short time ago, some limited experiments took place in some countries; in particular, we mention the distinguished Jordanian experience, which made it possible to use greywater to irrigate some trees, such as olive trees, after storage and treatment [9]. Some applications were also carried out in Tunisia, including a project called "The Nature Based Solutions for Domestic Water Reuse in Mediterranean Countries (NAWAMED) [24]; Zer0-M, short for "Sustainable Concepts Towards a Zero Outflow Municipality" [8]; etc. Keeping in view the opportunities in greywater research, this study focused on evaluating the purification performance of a vertical greywater treatment system installed in Soukra by studying the effect of irrigation with TGW on two varieties of olives.

2. Materials and Methods

2.1. Experiment Site and Plant Material

The study was carried out from 2014 to 2019 in a household in the Soukra area, located 6 km north-east of Tunis City. The region, characterized by Mediterranean climate, receives around 470 mm/year of rain and loses around 1450 mm/year of potential evapotranspiration.

The area covers approximately 2130 m^2 affected by shallow saline groundwater with an initial altitude of 2.20 m. An amendment of the soil with an elevation of 1 m made it possible to plant, in October 2010, two varieties of olive trees in 5 lines: 36 Picholine variety and 30 Chétoui variety.

The plot was divided into two parts; the first part of trees (15 Chétoui and 18 Picholine) was irrigated with treated greywater (ITGW) and the second part of trees (15 Chétoui, 18 Picholine), not irrigated and under natural conditions, received only rainwater. The latter is considered the control. Olive trees were irrigated by drip irrigation from April to September.

2.2. Greywater Origin and Treatment Unit

The treatment unit was initially set up in 2007 as part of a project called "Pure-Valorization of rainwaters and greywaters in Soukra", supported by the International Development Research Center (CRDI). As shown in Figure 1, the greywater is collected from the kitchen and washbasins; the treatment system operated with a greywater inlet flow rate of 500 L/day and a water residence period of around 1 day. This system included a 1000 L sedimentation tanks, two 500 L vertical flow beds (1 m $\times$ 1.2 m) in series, and an 8000 L rectangle tank for treated greywater. Each bed was filled with a sequence of layers of 15 cm gravel, 60 cm sand, 15 cm gravel, and a storage pool/tank. Each bed was 1 m^2 and contained around 10 potted seedlings of common reeds. A total amount of 500 L of greywater per day was pumped from the storage tank of raw greywater and supplied to the root zone of the first created vertical flow wetlands (first bed), where it flowed down through the two-layer filter to the storage. A polyvinyl chloride pipe with a diameter of 20 mm was used to provide a continuous supply of greywater to the vertical flow. The vertical flow wetlands were constructed longitudinally to regulate the flow of water in each location in the beds. The treated greywater drained from the second bed to the post treatment storage basin, where it was reused for the irrigation of olive trees.

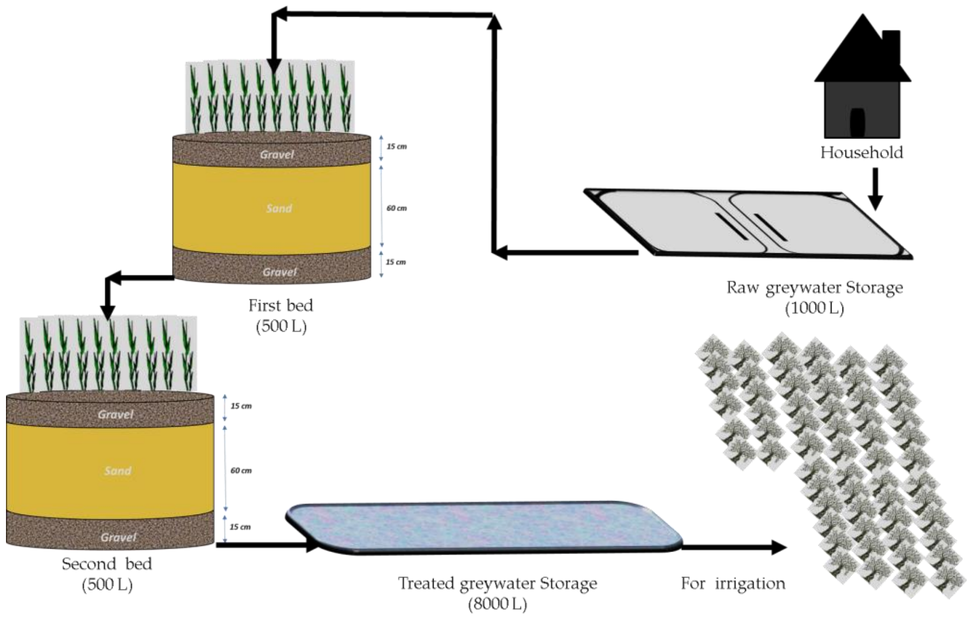


Figure 1. Scheme of greywater treatment unit.

2.3. Sampling and Analysis

2.3.1. Greywaters

Sampling of greywater was conducted during 2014–2017 and 2019. For 2018, the monitoring of the quality of greywater was not regular. Deep cleaning was carried out for the vertical treatment system; therefore, the data of 2018 was not taken into consideration for the water quality. However, olive tree growth and harvesting parameters were monitored from 2015 to 2019.

Analysis of the quality was carried out before (UGW) and after treatment (TGW). The samples were taken in sterile glass bottles with a capacity of 1 L. Additional potable water (PW) samples were also analyzed to compare this water with UGW evacuated from the household. The analyzes included pH, electrical conductivity (ECw), soluble salts (Ca^{2+}, Mg^{2+}, Na^+, K^+, HCO_3^-, $H_2SO_4^-$, Cl^-), heavy metals (Cd, Cu, Co, Cr, Fe, Mn, Ni, Pb, Zn), biological oxygen demand (BOD_5), chemical oxygen demand (COD), total bacteria (TC), feacal bacteria, feacal streptococus (FC), and Escherichia coli (*E.coli*). The measurement of pH was made using the electrometric method with a direct reading pH meter (NF ISO 10,390 2005). ECw was determined using a conductivity−meter, water quality meter pen type (model 8361, Cond & TDS). Calcium (Ca^{2+}) and magnesium (Mg^{2+}) were measured using complexometry in the presence of ethylenediamine tetraacetic acid (EDTA). Sodium (Na^+) and potassium (K^+) were determined with a flame photometer, type JENWAY PFP7 (NF-A20-603). Bicarbonate (HCO_3^-) was measured using titration with sulfuric acid (H_2SO_4) in the presence of methyl orange and phenolphthalein. Chloride (Cl^-) was measured using precipitation titration in the presence of silver nitrate ($AgNO_3$). Sulfate (SO_4^{2-}) was determined using nephelometry in the presence of 0.1 N hydrochloric acid and the dosage was carried out with the spectrometer, type UV-VIS, at 650 nm. Heavy metals were determined using emission flame spectrophotometry (Jenway, PFP7) and atomic absorption spectrometry (Perkin Elmer). BOD_5 and COD were determined according to the standard NF EN 1899-1 (version May 1998) and measured with an oxitop (Inductive Stirring System). The enumeration of bacteria for greywater quality is monitored according to the NPP method for UGW and TGW. Techniques and selected parameters were considered, following the recommendations of international regulations [8,25].

2.3.2. Olive Trees

The growth of each tree was measured: the trunk diameter D (cm), taken at a height of 5 cm from the level of the ground; and the vegetation height H (m), measured from the end of the tree trunk. For each tree, the olives were collected [26,27].

2.4. Statistical Analysis

Data analysis was performed using R 3.2.2 software (2015-08-14) to compare the greywater qualities. For microbiological and tree growth parameters, data were analyzed using the analysis of variance (ANOVA) and the Tukey test at the 5% significance level. Data were analyzed using SPSS software (IBM SPSS statistics, v20). Statistical analyses included descriptive statistics: average, minimum, maximum, standard deviation, and coefficient of variation (CV).

3. Results and Discussion

3.1. Greywater Treatment

The quality of greywater before (UGW) and after treatment (TGW) was assessed for reuse in irrigation according to the Tunisian Standard NT 106.03 and the World Health Organization (WHO) [8] (Table 1). To estimate the degradation of the quality by domestic activities, potable water (PW) was also analyzed.

Table 1. Physicochemical and microbiological characteristics of the greywater.

Parameter	Unit of Measurement	2014		2015		2016		2017		2019		PW	NT106.03	WHO
		UGW	TGW	UGW	TGW	UGW	TGW	UGW	TGW	UGW	TGW	-	-	-
Physicochemical parameters														
pH	-	7.54	7.47	7.87	8.09	7.33	7.86	7.96	8.28	7.39	7.66	7.69	6.5–8.5	6.5–8
EC	dS/m	2.25	2.52	1.65	2.14	2.33	2.46	2.37	2.43	2.56	2.77	0.56	7	0.7–3
Cl^-	me/L	6.07	15.80	10.27	21.14	6.07	1.99	9.95	12.18	10.99	12.38	5.93	700	140–350
HCO_3^-	me/L	8.86	13.09	11.57	11.98	7.98	8.69	7.71	5.69	9.87	10.35	3.32	ND	ND
SO_4^{2-}	me/L	7.74	6.58	4.83	6.10	7.74	4.78	7.09	6.32	7.74	9.42	3.07	ND	ND
Ca^{2+}	me/L	1.22	4.32	5.24	6.25	11.22	4.98	4.79	4.37	7.07	6.95	2.16	ND	ND
Mg^{2+}	me/L	9.21	1.30	1.76	2.19	9.21	1.40	3.49	3.11	1.24	0.66	2.19	50	ND
K^+	me/L	12.78	1.70	2.10	2.10	12.78	1.28	0.74	1.00	0.80	1.41	0.22	50	ND
Na^+	me/L	9.48	32.80	16.43	18.07	9.48	19.15	15.72	1.22	26.87	19.96	2.18	300	96–207
SAR	ratio	16.07	19.83	9.14	9.40	17.19	12.23	8.00	9.99	13.08	10.94	1.48	ND	<13
Cd	mg/L	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	-	0.01	<0.01
Cu	mg/L	0.02	0.01	0.01	0.00	0.31	0.04	0.09	0.01	0.14	0.00	-	0.5	ND
Co	mg/L	0.02	0.05	0.02	0.03	0.02	0.02	0.02	0.03	-	-	-	0.1	ND
Cr	mg/L	0.03	0.03	0.03	0.03	0.04	0.03	0.02	0.05	-	-	-	0.1	ND
Fe	mg/L	0.16	1.40	0.40	0.30	0.25	0.28	0.28	0.34	-	-	-	5	0.1–1.5
Mn	mg/L	0.14	0.07	0.16	0.06	0.05	0.08	0.06	0.14	-	-	-	0.5	ND
Ni	mg/L	0.04	0.07	0.04	0.04	0.04	0.04	0.03	0.07	-	-	-	0.2	ND
Pb	mg/L	0.03	0.04	0.04	0.04	0.03	0.04	0.04	0.07	-	-	-	1	<5
Zn	mg/L	0.04	0.07	0.05	0.06	0.05	0.06	0.04	0.26	-	-	-	5	<2
Biological parameters														
BOD_5	mgO_2/L	116.16	14.01	112.73	11.4	172.95	17.00	203.00	17.59	197.36	16.58	0.58	30	ND
COD	mgO_2/L	239.96	39.37	213.65	33.08	246.19	56.50	236.62	56.07	514.36	62.90	6.07	90	ND
Microbiological parameters														
TC	log10/100 mL	-	-	3.15	3.04	2.81	0.54	2.80	1.59	3.62	0.52	-	ND	ND
FC	log10/100 mL	-	-	0.66	1.36	0.79	0.57	0.73	0.37	0.79	1.35	-	ND	ND
SF	log10/100 mL	-	-	1.04	1.54	0.64	0.53	0.60	0.35	0.56	1.05	-	ND	ND
E. coli	log10/100 mL	-	-	1.08	1.08	0.75	0.58	0.71	0.58	0.68	0.78	-	ND	10^4–10^5

UGW showed high variability with an average pH of 7.62 and ECw of 2.23 dS/m. After treatment, pH and ECw showed a slight increase. The pH remained basic (7.87) and conformed to the Tunisian standard NT106.03. The slight increase in TGW pH has been observed by several authors [28]. The same trend was observed for ECw of TGW, with a slight increase (ECw = 2.46 dS/m) compared with UGW (Figure 2). It can be induced by detergent soaps from dishwashers or laundry [29,30], depending on the aging of the treatment system. Vegetation in the beds and evaporation may also contribute to this increase. Salinity of greywater is marked by a high concentration of Cl^- and Na^+, which can contribute damage to irrigated soils and plants [31].

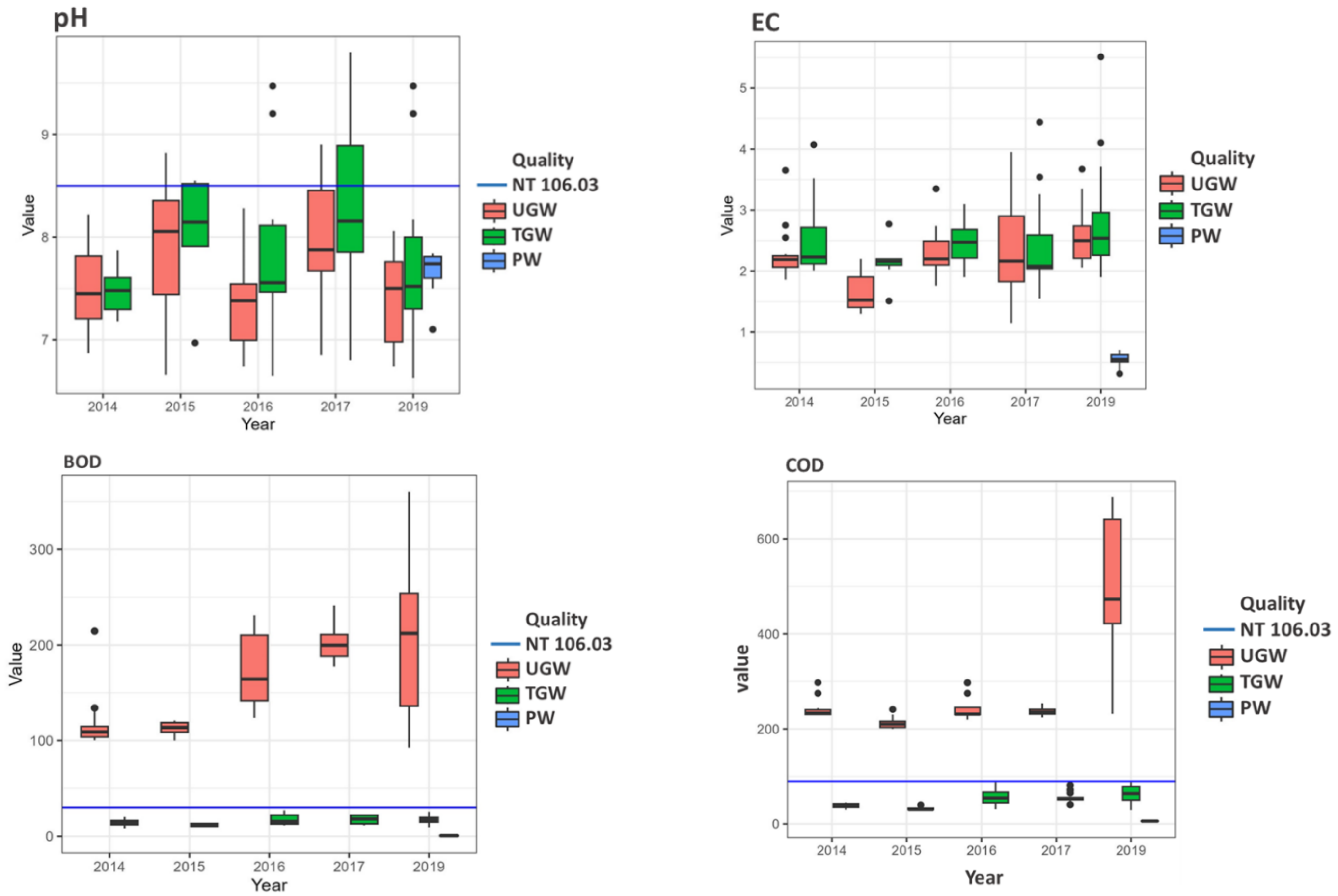


Figure 2. Boxplots of pH, ECw, BOD_5, and COD for greywater before (UGW) and after treatment (TGW).

Heavy metals were detected at low concentrations for UGW. Their concentrations increase after treatment. However, it was found that all of them were less than the standards (Table 1). Kananke et al. 2014 [32,33] found similar results and indicated that Cd, Cr, Cu, Pb, and Zn are at low concentrations in greywater.

The biological parameters (COD and BOD_5) of the TGW are lower than the BOD_5 and the COD of the UGW during the monitoring period (Figure 2). For BOD_5, a reduction in average content ranging from 160.44 mgO_2/L for UGW to 15.32 mgO_2/L for TGW was observed. The average removal of BOD_5 was 90% for the entire experiment period. The same trend was also observed for the COD which recorded an average value ranging from 290.15 mgO_2/L for the UGW up to 49.58 mgO_2/L, giving a removal average rate of 83%. For TGW, neither of these two parameters exceeded the standard recommendation, which requires a maximum value of 30 mg O_2/L for BOD_5 and 90 mgO_2/L for COD. These results prove the good performance of the treatment system used in this work. It has a stronger ability to remove organic load, proven by physical processes (sedimentation and filtration) combined with biological processes (role of macrophytes) [34]. Our results concord with other studies. Shaikh and Ahmad [35] declared the best purification performance at the vertical flow filter with the removal of BOD_5 and COD up to 74% and 88%, respectively. Another study has shown a reduction in organic load of up to 76% for COD and 83% for BOD_5 [36].

Microbiological risk in greywater was also taken into consideration and pathogenic organisms were monitored (Table 2). The presence of these pathogens in water at concentrations above the standards can cause problems at different levels. Results showed a very high variations in this study and several other studies [37]. The highest removal was reported for TC. This was not the case in Verma et al. [38] who observed the highest elimination for *E.coli*. From Table 2, it can be seen that the log_{10} removal unit in greywater before treatment ranged from 3.07 ± 0.74 for FC and 3.33 ± 0.81 for *E.coli*, leading to removal units of 2.44 ± 0.91 for FC and 2.73 ± 0.75 for *E. coli* after treatment. As for FS, it could be seen that the log_{10} removal unit from 2.89 ± 0.71 for UGW to 2.53 ± 0.87. Overall, results obtained showed that the use of a vertical greywater treatment system allowed high levels of elimination for indicator bacteria and pathogens; however, this remains insufficient for the four germs that were detected after treatment.

Table 2. Average bacteria removal efficiency in vertical greywater treatment system.

	TC	**FC**	***E. coli***	**FS**
UGW log_{10} unit Average	3.09 ± 0.87 a *	3.07 ± 0.74 a	3.33 ± 0.81 a	2.89 ± 0.71 a
TGW log_{10} unit Average	1.42 ± 0.63 b	2.44 ± 0.91 ab	2.73 ± 0.75 ab	2.53 ± 0.87 a

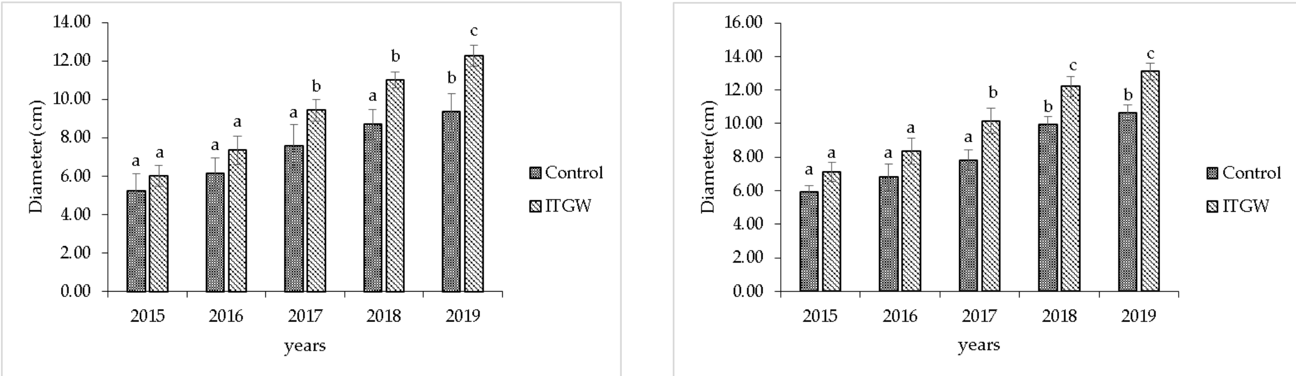
* Results are presented as means ± SD (n = 3). a, b: within each column, mean values followed by the same letter are not significantly different according to the Tukey test at $p < 0.05$. Total coliforms (TB), fecal coliforms (FC), Escherichia coli (*E.coli*), faecal streptococci (FS).

3.2. Valorization of Treated Greywater

3.2.1. Growth Parameters of Olive Trees: Diameter (D) and Height (H) of Trees

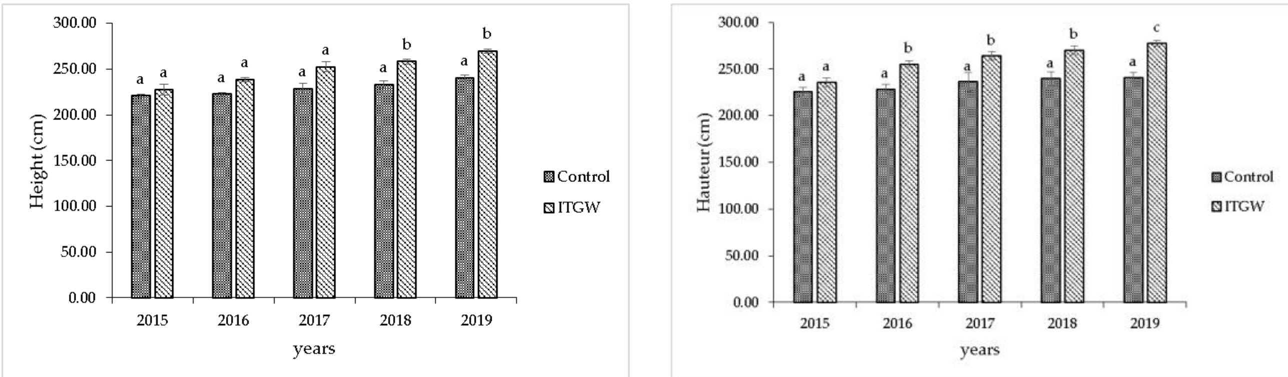
The TGW has a positive effect on the D of olive trees, whatever the variety, which in turn may affect production. For the chétoui variety, the average D of ITGW olive trees was 6.07 m in 2015 and increased considerably to reach 12.24 m in 2019, while showing a gap of almost double (Figure 3a). By comparison to the controls, we see that the average diameter of ITGW olive trees increases by 15.4% in 2015, 19.4% in 2016, 24.8% in 2017, 26.7% for 2018, and 31.2% in 2019. The same result was observed for the picholine variety; the average D increased from 7.12 m in 2015 to 13.11 m in 2019, with a gradual increase during the experiment of 20.3% in 2015, 23% in 2016, 29.5% in 2017, 22.9% in 2018, and 23.2% in 2019 (Figure 3b). The results also show that there is a significant ($p \leq 0.05$) difference in SD amongst the two water treatments used throughout the monitoring period (Figure 3). Our results confirm the observations of several authors [39], who recorded a greater diameter in piper irrigated with TGW than those irrigated with raw water and freshwater, contrary to other researchers [40] who found the better growth D in vegetation irrigated with UGW than those of TGW.

As for D, the results showed that H of the different olive trees increased after treatment, for all types of irrigation during all years of experimentation (Figure 4). For the chétoui variety, the values of H for olive trees ITGW varied from 227.52 cm in 2015 to 269.64 cm in 2019, with an average increase of 3.08% in 2015, 7.21% in 2016, 10.32% in 2017, 10.83% in 2018, and 12.19% in 2019 (Figure 4a). H of the picholine variety was also determined in this study as having a value of 235.74 cm in 2015 and 277.44 cm in 2019, with an increase of 4.60% in 2015, 11.63% in 2016, 11, 68% in 2017, 12.74% in 2018, and 15.06% in 2019 (Figure 4b). A significant ($p \leq 0.05$) difference in H was observed for the two water treatments used. These results are in agreement with those found by Mzini and Winter [41], who reported higher height for carrots irrigated with TGW than those irrigated with potable water. Alao et al. [39] also reported similar results in an experiment conducted on peppers. These researchers recorded a significant increase in the H of pipers irrigated with TGW compared to those irrigated with UGW.



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

Figure 3. Variation of the diameter (D) of the two varieties of olive trees during the period 2015–2019: (**a**) Chétoui; (**b**) Picholine.



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

Figure 4. Variation in Height (H) of the two varieties of olive trees during the period 2015–2019: (**a**) Chétoui; (**b**) Picholine.

3.2.2. Olive Trees Production

The effect of irrigation with TGW on olive production is shown in Table 3. Olive production was significantly influenced by the use of greywater for irrigation. This is expressed by the results observed during the experiment.

For Chétoui, olive production increased from 13.92 kg in 2015 to 73.11 kg in 2019 for the control and from 26.77 kg in 2015 to 112.41 kg in 2019 for the ITGW. The same things was observed for Picholine, in which olive production increased from 25.00 kg in 2015 to 79.69 kg in 2019 for the control and from 39.12 kg in 2015 to 146.15 kg for ITGW. These results recall the results of other authors [42], who studied the effect of irrigation on olive trees (Nabali variety) with 3 types of water, observing the best production in olive trees irrigated by TGW. From Table 4, we deduce that there is a very significant effect of irrigation with TGW on olive production compared to the control.

Table 3. Production (kg) of olive varieties conducted under TGW irrigation and natural conditions.

Year	2016	2017	2018	2019
		Chétoui		
N olive trees	15	15	15	15
Control	13.92	59.71	64.51	73.11
ITGW	26.77	93.24	104.5	112.41
Olive Production (kg)	40.69	152.95	169.01	185.52
		Picholine		
N olive trees	18	18	18	18
Control	25	63.62	72.45	79.69
ITGW	39.12	108.07	126.30	146.15
Olive production (kg)	64.12	171.69	198.75	225.84
Annual olive production (kg)	104.81	324.64	367.76	411.36

N olive trees: Number of olive trees used in this study.

Table 4. Average olive production of two varieties, Chétoui and Picholine, under irrigation with TGW.

	Chétoui		Picholine	
	Control	ITGW	Control	ITGW
N olives trees	15	15	18	18
Average	52.2 ± 26.51 a	84.23 ± 39.10 b	60.19 ± 24.36 a	104.91 ± 46.53 b
CV%	50.79	46.42	40.47	44.35

Results are presented as means ± SD (n = 3). a, b: within each column, mean values followed by the same letter are not significantly different according to the Tukey test at $p < 0.05$. N olive trees: number of trees used in this study.

The results noted that the best response was observed for the Picholine variety for growth parameters and olives production (Figure 5).

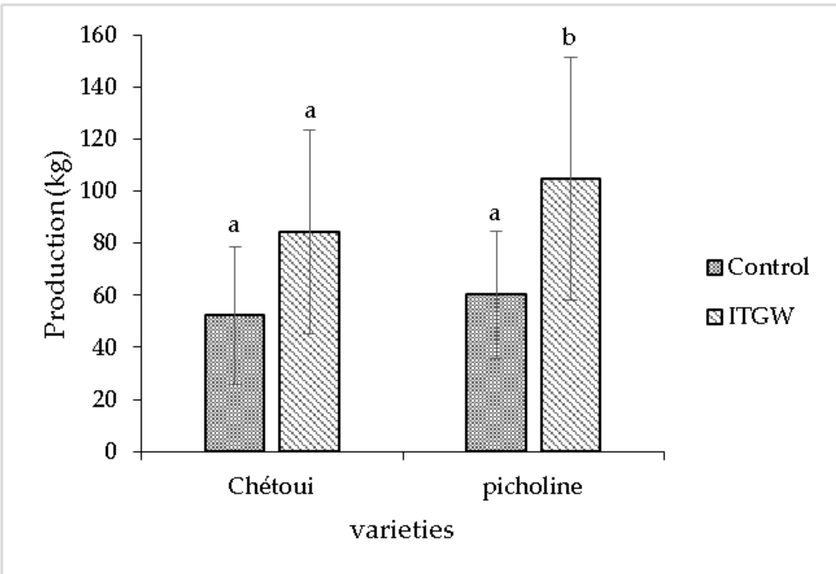


Figure 5. Average olive production of two varieties, Chétoui and Picholine, under irrigation with TGW.

4. Conclusions

This study aimed to evaluate the performance of a vertical treatment system for purifying greywater in a household, and to investigate the effects of irrigation with TGW on some growth parameters and on the productivity of olive trees. The results showed that all the chemical parameters of TGW, including pH, ECw, soluble salts, heavy metals, COD, and BOD_5, were within the allowable limits of the Tunisian standards NT 106.03 for the reuse of wastewater in agriculture. This confirms the effectiveness of vertical greywater treatment systems that implement reed-planted filters. The microbiological examination of TGW revealed that it was of insufficiency quality for agricultural use, despite the decrease in the microbiological indicators from 1 to 3 logarithmic units. To improve this aspect, it will be better to increase the density of macrophytes in the treatment system and to add a disinfection system, such as a UV system. It was also found that the growth parameters of two varieties of olives were more greatly improved under irrigation with TGW compared to those under natural conditions. It was also observed that the quality of TGW had considerable effect on the productivity of olives, whatever the variety. Therefore, we conclude that the results support the possibility of greywater reuse for irrigation purposes if adequate treatment techniques are used. Nevertheless, a health control must be imposed to reduce health risks.

Author Contributions: Conceptualization, H.F. and M.H.; methodology, H.F.; software, H.F., G.H. and N.B.; validation, M.H. and V.N.; formal analysis, H.F.; investigation, H.F.; resources, N.B. and F.N.; data curation, H.F.; writing—original draft preparation, H.F.; writing—review and editing, N.B.; supervision, M.H.; funding acquisition, N.B. and O.I. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Not applicable.

Acknowledgments: Authors thank all colleagues and the technical staff at the Laboratory of Non-Conventional Water Valorization–INRGREF (Tunisia) for water sampling and analysis. We also wish to express our gratitude to the Department of Environmental Engineering and Mechanical Engineering of the "Vasile Alecsandri" University of Bacau (Romania).

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

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