sustainability

MDPI

Article

Wastewater Treatment Performance of Aerated Lagoons, Activated Sludge and Constructed Wetlands under an Arid Algerian Climate

Oum Elkheir Bachi [1,2,*], Mohammed Tahar Halilat [1], Samia Bissati [1], Nadhir Al-Ansari [3,*], Sofiane Saggai [4], Saber Kouadri [4] and Hadee Mohammed Najm [5]

1. Laboratory of Saharan Bio-Resources: Preservation and Valorization (BRS), University Kasdi Merbah, Ouargla 30000, Algeria
2. Agricultural Development Commission in the Saharan Regions (CDARS), Ouargla 30000, Algeria
3. Department of Civil Environmental and Natural Resources Engineering, Lulea University of Technology, 97187 Lulea, Sweden
4. Laboratory of Water and Environment Engineering in Sahara Milieu (GEEMS), University of Kasdi Merbah, Ouargla 30000, Algeria
5. Department of Civil Engineering, Zakir Husain Engineering College, Aligarh Muslim University, Aligarh 202002, India

* Correspondence: nawelecol@yahoo.fr (O.E.B.); nadhir.alansari@ltu.se (N.A.-A.)

Abstract: Water pollution reduces the availability of fresh water, especially in arid areas suffering from water stress, and also adversely affects soil, vegetation and environmental processes. Wastewater treatment processes aim to reduce environmental degradation and increase water availability by improving the quality of wastewater to a standard suitable for irrigation. This paper compares the performance of three wastewater treatment processes: (i) aerated lagoon (AL), (ii) activated sludge (AS), and (iii) constructed wetland (plant beds, PB) under the arid climate of Algeria. The statistical analysis focused on the comparison between the removal rates of the physical (SS) and biological pollution (BOD_5 and COD) parameters in the three stations during 8 years of operation. Obtained results show that the maximum removal rates were observed in the AS process and the minimum were in the AL process. The comparison between the removal rates for a given parameter has shown that there is a significant difference between the AL process on the one hand and the AS and PB processes on the other hand. For the last two processes, AS and PB, there is a difference, but it is not statistically significant. For the values of the parameters of wastewater leaving the three systems, results showed that there is a seasonal variation in the average values of the parameters (temperature effect) and that with the exception of orthophosphate, the values recorded are, for the most part, below the values of Algerian discharge standards, WHO standards and FAO standards.

Keywords: wastewater; removal rate; treatment processes; ANOVA; arid climate

Citation: Bachi, O.E.; Halilat, M.T.; Bissati, S.; Al-Ansari, N.; Saggai, S.; Kouadri, S.; Najm, H.M. Wastewater Treatment Performance of Aerated Lagoons, Activated Sludge and Constructed Wetlands under an Arid Algerian Climate. *Sustainability* **2022**, *14*, 16503. https://doi.org/10.3390/su142416503

Academic Editors: Anna Laura Eusebi, Nicola Frison, Çağrı Akyol and Vincenzo Torretta

Received: 26 August 2022
Accepted: 6 December 2022
Published: 9 December 2022

1. Introduction

The end of the 1960s marked the rise of drainage and sanitation networks in the province of Ouargla, Algeria. During that decade, these networks were extended to evacuate the excesses generated by the rise in the water table due to the irrational exploitation of the fossil aquifers [1–3]. These networks aim to keep wastewater away from homes and the urban environment, but very quickly the problem of the fate of this wastewater arises [4,5].

Previously, accumulated wastewater was discharged into the wild in its raw state: in the natural lagoon of Oum Erraneb in Ouargla [6] and in the Oued Righ canal in Touggourt [7,8]. They were also used sometimes, in their raw state, in irrigation. This situation was not only responsible for the degradation of soil, environment and buildings, but also for the genesis of waterborne diseases (cholera, typhoid, etc.) [9,10].

Wastewater treatment, which is a set of techniques that reduce and/or eliminate pollutants in water in order to reuse it in agriculture or to discharge into the environment without having negative consequences [11,12], is the solution that protects the environment and therefore human beings. For this, five treatment plants were built in the two cities of Ouargla and Touggourt (three in Ouargla and two in Touggourt). The methods adopted in these five stations include three biological wastewater treatment processes: aerated lagoon (AL), activated sludge (AS) and constructed wetland system (by reed bed and by plants bed "PB").

Several researchers around the world have studied the performance of wastewater treatment processes to assess their effectiveness and determine the fate of treated wastewater [13–17]. For our regions of Ouargla and Touggourt, research studies on the performance of the various wastewater treatment processes mentioned began with the construction of wastewater treatment plants (WWTP) as part of a mega-project to fight water upwelling [18,19].

The particularity and the novelty of the present study is in: (i) the evaluation of the three processes during eight years of service under an arid climate based on the statistical study which allows clearly visualizing the difference, if it exists, between the three processes; (ii) detection of a seasonal variety effect on wastewater treatment processes; and (iii) definition of the most appropriate process for the arid climate conditions of our region.

2. Methodology

2.1. Study Area

The three wastewater treatment plants (WWTP) of our study are located in the Ouargla Department. This Department is located in the Algerian Sahara, and it is characterized by an arid climate (AI < 5 De Martonne E. [20]) and long periods of drought (See Figure 1).

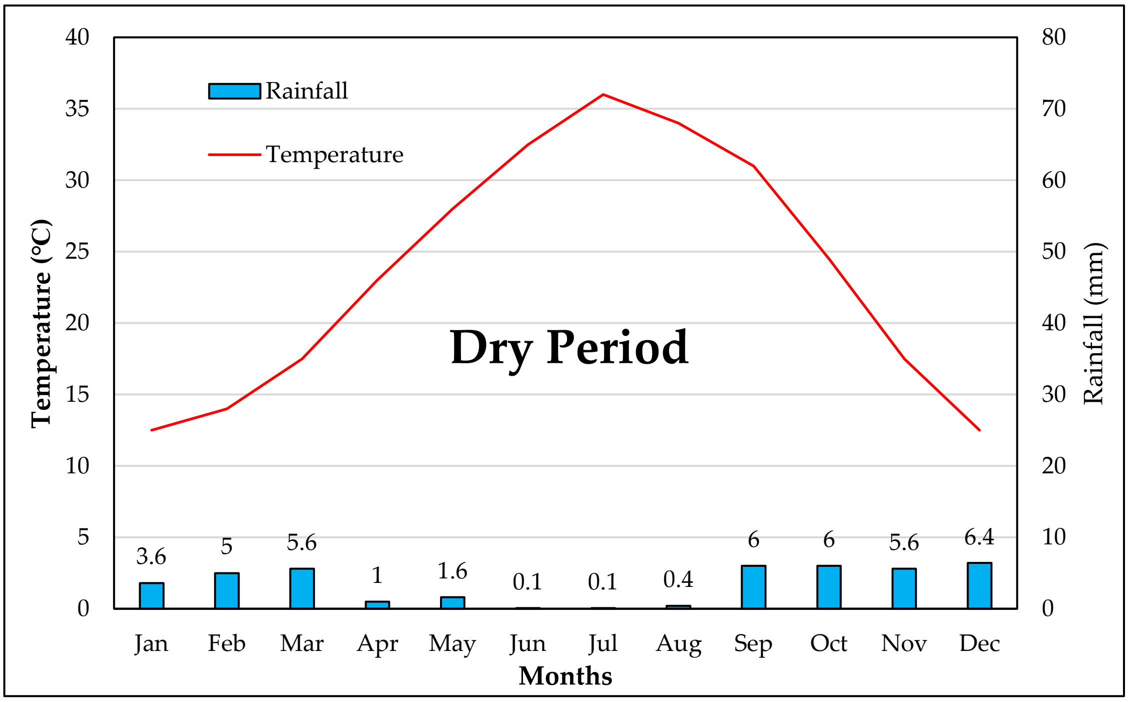

Figure 1. Ombrothermal diagram of Ouargla Department (2011–2018).

According to Figure 1, rainfall is scant in the Ouargla region. Collected data of 8 years shows that the annual average sum is 33.7 mm (269.5 mm for 8 years).

2.2. Presentation of Studied Wastewater Treatment Plants

The three wastewater treatment plants (WWTP) are distributed in the Ouargla Department as follows: (i) The aerated lagoon process treatment plant is located in the city of Ouargla (31.997° N, 5.368° E). It is of a conceptual capacity of 400,000 inhabitant equivalent (IE), and it treats an average daily volume of more than 39,000 m^3 which represents 260,000 IE. (ii) The activated sludge process treatment plant is located in the town of Tougourt (33.103° N, 6.088° E). It has of a conceptual capacity of 62,500 IE, and it treats an average volume of 9300 m^3/day which represents 62,000 IE. (iii) The constructed wetland (plant bed, PB) is located in Temacine (33.018° N, 6.019° E). It has a conceptual capacity of 100 IE, and it purifies an average volume of 14 m^3. Therefore, its inhabitant equivalent is 93.

2.3. Data Collection and Analysis

Water samples were taken once a week at the inlet and outlet of the WWTPs over 8 years, using 5 L grab samples. Each sample was analyzed within 1 day of collection for suspended solids (SS), the 5-day biochemical oxygen demand (BOD_5), the chemical oxygen demand (COD), nitrate and nitrite nitrogen (NO_3^- and NO_2^-) and orthophosphate (PO_4^{3-}). All analyses were performed according to standard methods for the examination of water and wastewater of the American Public Health Association (APHA) and the United States Environmental Protection Agency (USEPA), all methods are mentioned in Table 1.

Table 1. Parameters and analysis methods.

Pollution Parameters	Test Methods
BOD_5 (mg/L)	Standard Methods for the Examination of Water and Wastewater. File 5210B
COD (mg/L)	Standard Methods for the Examination of Water and Wastewater. File 5220B
SS (mg/L)	Standard Methods for the Examination of Water and Wastewater. File 2540D
Nitrogen (Nitrite) (mg/L)	United States Environmental Protection Agency (USEPA) Diazotization Method Federal Register, 44(85), 25,505, 0.002 to 0.300 mg/L NO_2^--N by Spectrophotometer
Nitrogen (Nitrate) (mg/L)	UV Screening Method Adapted from Standard Methods for the Examination of Water and Wastewater' Published by the American Public Health Association APHA Standard, Part 4500-NO3–B, 0.1 to 10.0 mg/L NO_3^--N by Spectrophotometer
Phosphorus (Orthophosphate) (mg/L)	USEPA PhosVer 3 Standard Procedure is Equivalent to USEPA and Standard Method 4500-P-E for Wastewater, 0.02 to 2.50 mg/L PO_4^{3-} by Spectrophotometer

2.4. Data Analyses Tools

The three WWTP used in this study are of different sizes. Therefore, the comparison can only be made between the purification removal rates of BOD_5, COD and SS and the quality of the water leaving the stations compared to the various existing standards.

To make analyses easy, the annual removal rate of each parameter was calculated using the values recorded at the input and output of each station.

To properly visualize the difference between the different adopted processes, a graphical method of descriptive statistics by boxplot and statistical analysis of variance (ANOVA) with the latest of the post hoc tests (the Fisher test called LSD (for Least Square difference)) were performed using SPSS Ver.22 software.

3. Results

3.1. Characterization of Influent

The rate of the organic load, which is the ratio of the pollution received over the nominal capacity of the plant, is expressed as a% of the nominal flow in BOD_5. The rates determined for the three plants of the three processes show that the organic loads of the raw wastewater entering the plants are lower than the nominal capacities of these plants. In addition, the COD/BOD_5 ratio values of the raw wastewater from the three stations are mostly less than three, which leads us to conclude that it is easily biodegradable raw wastewater.

3.2. Biological Oxygen Demand (BOD_5)

According to Tradat [21], Rejsek [22] and Clair et al. [23], BOD_5 is the amount of oxygen required to oxidize organic matter biologically calculated after 5 days at 20 °C and in the dark (oxidation of biodegradable organic matter by bacteria).

Figure 2 shows the variation of the percentage of BOD_5 elimination during 8 years for the three studied processes using the boxplot.

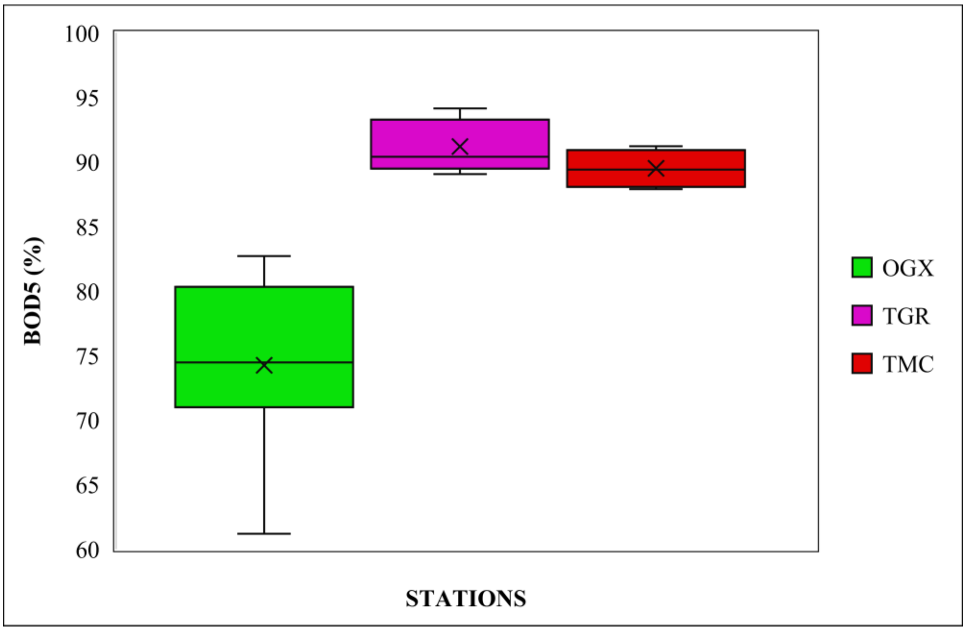

Figure 2. Boxplots of biological oxygen demand in five days (DBO_5) removal rates of the three processes.

According to Figure 2, the removal rate of BOD_5 is the highest for Touggourt station where an activated sludge process is used, and the lowest one is in the Ouargla station that uses an aerated lagoon process.

For the case of the aerated lagoon process (Ouargla "OGX" station), the median of the BOD_5 removal rate is slightly at the bottom of the box. So, this is an asymmetric distribution towards the low removal rate values of BOD_5. The large length of the box (61.2–82.7%) indicates a wide variability in the removal rate values of BOD_5 from the aerated lagoon process during the 8 years of the study.

With regard to the activated sludge process (Touggourt "TGR" station), the length of the box is relatively short (89.0–94.2%) compared to that of the aerated lagoon process, which means that there is little variability in the values of the BOD_5 removal rate for this process. The median for this activated sludge process is completely at the bottom of the box. Therefore, there is an asymmetric distribution towards the low removal rate values of BOD_5.

In the case of the plants bed process, the median is centered, which implies a symmetrical distribution of the BOD_5 removal rate values. For the length of the box, it is the lowest (87.9–91.2%) compared to the other two processes which means a low variability in the removal rate values of BOD_5 of the plants bed process.

The difference in removal rates is perhaps clear between Ouargla station and the two other stations of Touggourt and Témacine, but not really clear between Touggourt station and Témacine station. For that, a comparison between means of BOD_5 removal rates using one-way ANOVA is necessary to know whether the differences are significant.

The results of the comparison between methods s of BOD_5 removal rates using one-way ANOVA are presented in Tables 2 and 3.

Table 2. ANOVA of BOD_5 removal rates.

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	1394.048	2	697.024	39.999	0.000
Within Groups	365.950	21	17.426		
Total	1759.998	23			

Table 3. Multiple comparison of BOD_5 removal rates.

(I) Station	(J) Station	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
AL (OGX)	AS (TGR)	−16.94125 *	2.08723	0.000	−21.2819	−12.6006
	PB (TMC)	−15.26250 *	2.08723	0.000	−19.6031	−10.9219
AS (TGR)	AL (OGX)	16.94125 *	2.08723	0.000	12.6006	21.2819
	PB (TMC)	1.67875	2.08723	0.430	−2.6619	6.0194
PB (TMC)	AL (OGX)	15.26250 *	2.08723	0.000	10.9219	19.6031
	AS (TGR)	−1.67875	2.08723	0.430	−6.0194	2.6619

* The mean difference is significant at the 0.05 level.

According to the results in Table 2, the significance (0.000) is less than 0.05. This means that the BOD_5 removal rate averages for the different processes are different. However, the statistical significance between each pair of processes is not indicated in the table.

To see the significance between the BOD_5 removal rates of each pair of processes, we use Table 3 of multiple comparison of BOD_5 removal rates.

According to Table 3, the difference in the means of the OGX-TGR and OGX-TMC pairs is statistically significant; but it is not for the case of the TGR-TMC pair.

Figure 3 shows the seasonal variation of the BOD_5 of treated wastewater at the outlet of the three stations. The histograms represent the averages of eight years of study.

According to Figure 3, the maximum BOD_5 values for the four seasons are recorded in the Ouargla aerated lagoon station. For the minimum values, they are mostly recorded in the Témacine plants bed station during winter, spring and autumn.

Going from one season to another, the difference between the BOD_5 values is distinctive for the aerated lagoon and the plants bed. In the case of the activated sludge process, the values recorded in the four seasons are very close, and the difference between them is very small.

The minimum value of BOD_5 for the aerated lagoon process is recorded in the winter period, while that of the plants bed process is recorded in the spring period. The maximum values are observed in the summer period for the two processes mentioned.

Figure 3 also shows, through the error bars, that there is a wide variability between the BOD_5 values for the three processes.

Compared to the various standards relating to treated wastewater, the BOD_5 values of the water from the three processes are below the Algerian discharge standards (35 mg/L), but compared to the values of the discharge standards of WHO (30 mg/L) and the agricultural reuse standards of FAO [24] (30 mg/L), only the wastewater purified from the activated sludge and the plants bed processes meet these two standards.

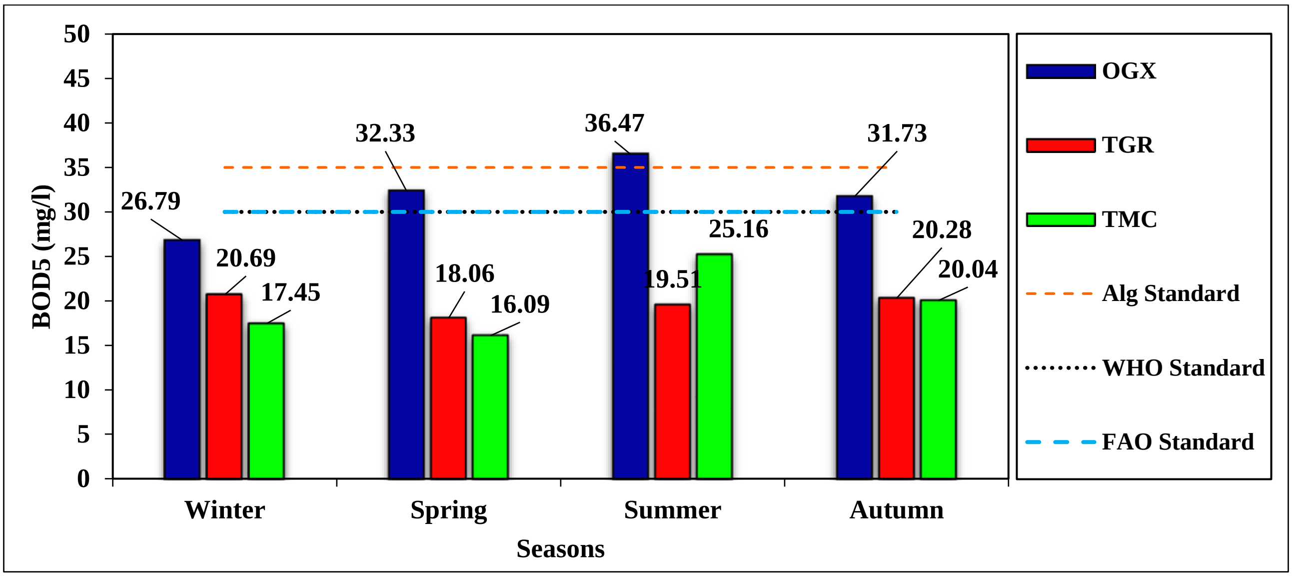

Figure 3. Values of BOD_5 recorded at the output of the stations of the three processes.

3.3. Chemical Oxygen Demand (COD)

Unlike BOD, COD does not simulate the biodegradation of organic matter easily decomposed by bacteria and other microorganisms present in a natural environment capable of inducing rapid de-oxygenation of an aquatic environment. It represents the consumption of oxygen by strong chemical oxidants to oxidize organic and mineral substances in water [22]. Figure 4 presents the variation of COD removal rates of the studied processes.

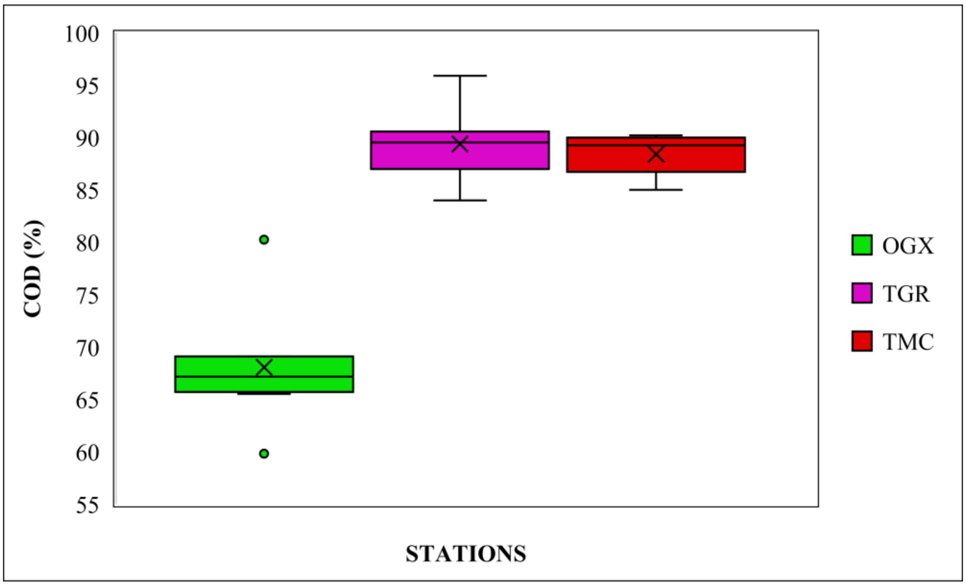

Figure 4. Boxplots of COD removal rates of the three processes.

According to Figure 4, removal rate of COD is the highest in the activated sludge process and the lowest one in the aerated lagoon.

In addition, according to Figure 4, the three boxes of the three processes are short in length (65.5–69.1% in OGX, 84.0–89.9% in TGR and 85.0–90.2% in TMC), which shows that there is a low variability in the COD removal rate values for the three processes. It is also observed that there is extreme values in the cases of the aerated lagoon (59.8% and 80.3%) and activated sludge (95.9%) processes. This may be due to data entry errors; otherwise, they are likely associated with measurement errors.

Figure 4 also shows that the COD removal rates in the Ouargla station are the lowest compared to those of the other two stations. The maximum removal rates are recorded in the Touggourt station, and they are close to those of Témacine.

For the type of distribution in a given process, Figure 4 indicates that the median is at the bottom of the box for the aerated lagoon, which means an asymmetric distribution towards the low values of COD removal rate. For the activated sludge and plants bed processes, the medians are at the top of the boxes, which indicates an asymmetric distribution towards the high removal rate values.

The difference in removal rates is perhaps clear between different processes, but we do not know if this difference in significant. For that, a comparison between the means of COD removal rates using one-way ANOVA is necessary.

Results of a comparison between the means of COD removal rates using one-way ANOVA are presented in Tables 4 and 5.

Table 4. ANOVA Of COD removal rates.

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	2321.320	2	1160.660	71.867	0.000
Within Groups	339.154	21	16.150		
Total	2660.475	23			

Table 5. Multiple Comparison of COD removal rates.

(I) Station	(J) Station	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
AL (OGX)	AS (TGR)	−21.33125 *	2.00937	0.000	−25.5100	−17.1525
	PB (TMC)	−20.36000 *	2.00937	0.000	−24.5387	−16.1813
AS (TGR)	AL (OGX)	21.33125 *	2.00937	0.000	17.1525	25.5100
	PB (TMC)	0.97125	2.00937	0.634	−3.2075	5.1500
PB (TMC)	AL (OGX)	20.36000 *	2.00937	0.000	16.1813	24.5387
	AS (TGR)	−0.97125	2.00937	0.634	−5.1500	3.2075

* The mean difference is significant at the 0.05 level.

Table 4 indicates that the COD removal rate averages for the different processes are significantly different. However, the statistical significance between each pair of processes is not indicated in the table.

To know the significance between the COD removal rates of each pair of processes, we use Table 5 of multiple comparison of COD removal rates.

According to Table 5, the difference in the means of COD for the OGX-TGR and OGX-TMC pairs is statistically significant; but it is not for the case of the TGR-TMC pair.

Figure 5 shows the averages of the COD values recorded between 2011 and 2018 in the three stations of our study.

Figure 5 shows that the maximum DOC values during the four seasons are observed in the aerated lagoon station. The minimum values are noted in the plants bed station.

The DOC values from one season to another are very variable for the aerated lagoon and the plants bed but relatively stable for the activated sludge process. The maximum values for the aerated lagoon and the plants bed are observed in summer, and the minimum values are observed in winter.

It is also noted in Figure 5, according to the error bars, that there is little variability in the values recorded during the eight years of the study.

From a quality point of view, Figure 5 shows that the COD values of purified wastewater from the Touggourt and Témacine stations are lower than the values of the Algerian standard [25] of rejection (120 mg/L), that of WHO [26] (90 mg/L) and that of FAO [24]

(40 mg/L). For the aerated lagoon in Ouargla, the values of the treated wastewater are mostly lower than the Algerian standard [25] but do not meet the standards of WHO [26] and FAO [24].

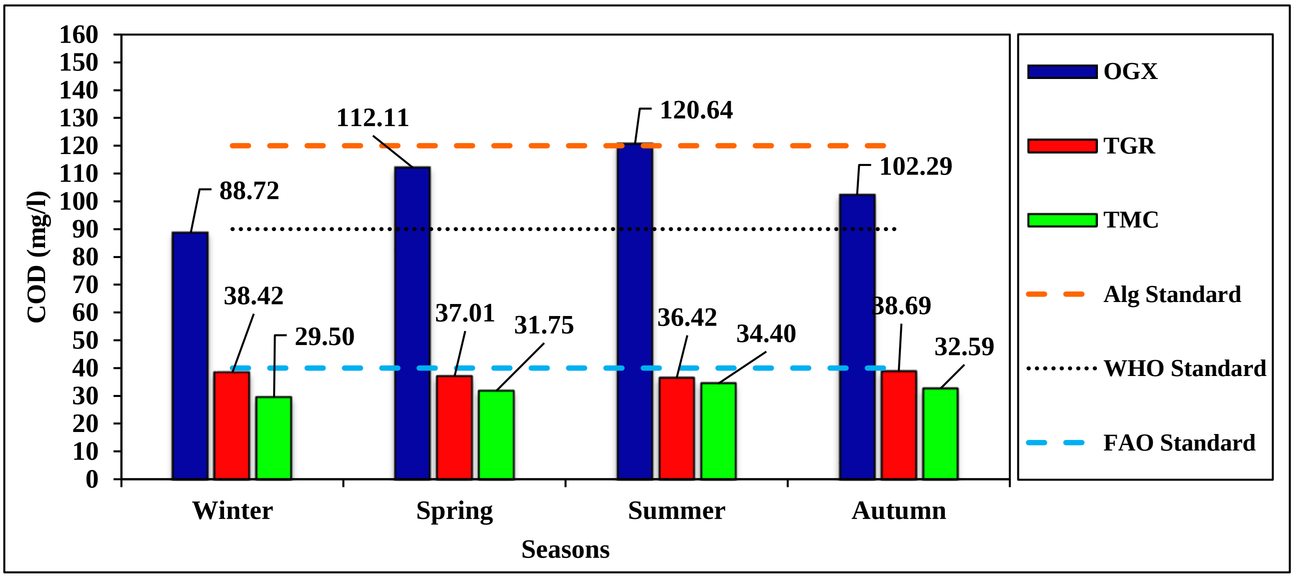

Figure 5. Values of COD recorded at the output of the stations of the three processes.

3.4. Suspended Solids

Figure 6 shows the variation of SS removal rates in the three processes.

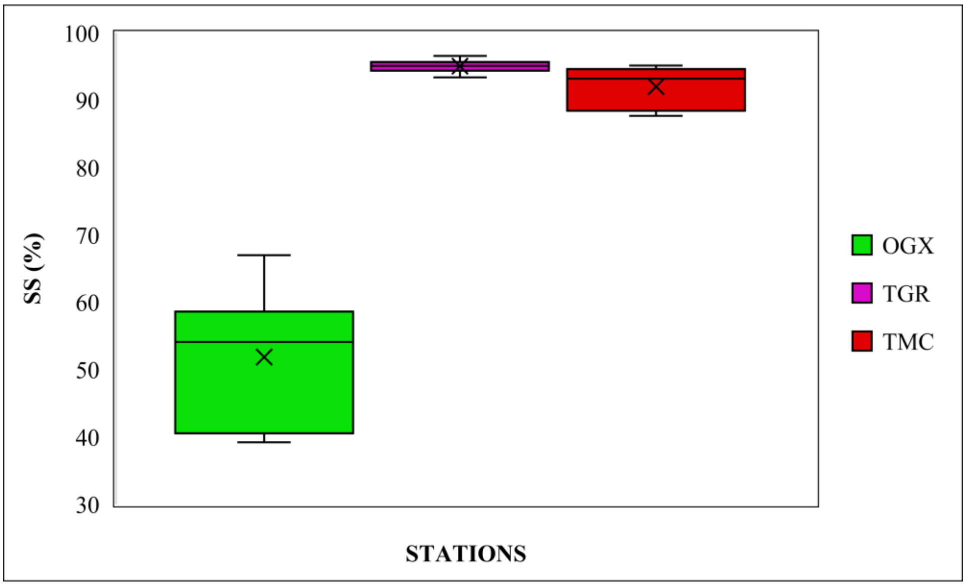

Figure 6. Boxplots of SS removal rates of the three processes.

Figure 6 shows that removal rates of SS are the highest for Touggourt station, and the lowest one is in the Ouargla station.

The boxplot presented in Figure 6 of the removal rates of SS show that there is wide variability in the values of the removal rate of SS for the aerated lagoon process (39.2–67%), low variability in the values of the removal rate for the process of plants bed (87.7–95.2%) and ultra-low variability in the removal rate values for activated sludge (93.4–96.9%).

Figure 6 also shows that the minimum removal rates are recorded in the Ouargla station and the maximums in the Touggourt station. For the Témacine station, the removal rate values are close to those of the Touggourt station.

It is also well observed in Figure 6 that the distributions of the removal rate values of SS are asymmetrical and towards the high removal rate values for the aerated lagoon and plants bed processes. For the case of the activated sludge process, the distribution of the removal rate values of SS is symmetrical.

There are differences between different groups of removal rates of processes. For that, a comparison between the means of SS removal rates using one-way ANOVA is necessary to know if differences are significant.

Results of comparison between the means of SS removal rates using one-way ANOVA are presented in Tables 6 and 7.

Table 6. ANOVA Of SS removal rates.

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	9310.668	2	4655.334	122.649	0.000
Within Groups	797.089	21	37.957		
Total	10,107.757	23			

Table 7. Multiple comparison of COD removal rates.

(I) Station	(J) Station	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
AL (OGX)	AS (TGR)	−43.23250 *	3.08045	0.000	−49.6386	−36.8264
	PB (TMC)	−40.16250 *	3.08045	0.000	−46.5686	−33.7564
AS (TGR)	AL (OGX)	43.23250 *	3.08045	0.000	36.8264	49.6386
	PB (TMC)	3.07000	3.08045	0.330	−3.3361	9.4761
PB (TMC)	AL (OGX)	40.16250 *	3.08045	0.000	33.7564	46.5686
	AS (TGR)	−3.07000	3.08045	0.330	−9.4761	3.3361

* The mean difference is significant at the 0.05 level.

Table 6 points out that SS removal rate averages for the different processes are significantly different. However, the statistical significance between each pair of processes is not indicated in the table.

To check the significance between the SS removal rates of each pair of processes, we use Table 7 of multiple comparison of SS removal rates. Figure 7 summarizes the SS results from the different stations.

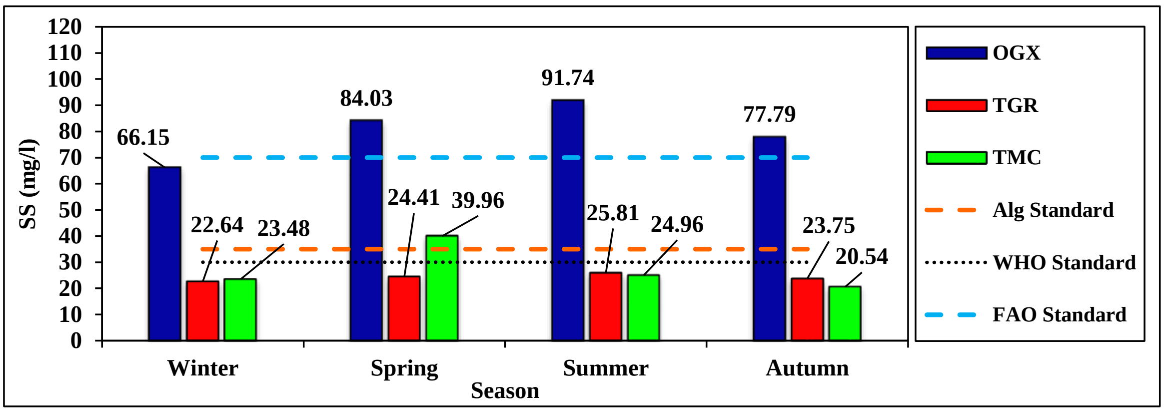

Figure 7. Values of SS recorded at the output of the stations of the three processes.

According to Figure 7, the average values of SS at the exit from the stations of our study are maximum in the four seasons at the Ouargla station, while the minimum values are only visualized for a single station during the four seasons.

From one season to another, we notice a great variability between the values of SS for the aerated lagoon processes and the plants bed. This variability is absent for an activated sludge station.

Winter is the season marked by the minimum average value for the aerated lagoon process, and summer is marked by its maximum value. For plants bed, the maximum average value is observed in spring, while the minimum is noted in autumn.

For the variability of the SS values recorded during the period 2011–2018, the error bars in Figure 7 show that it is very wide the aerated lagoon station and very short for the activated sludge processes and the plants bed except for spring for the latter.

Regarding the standards, the SS values of the treated wastewater from the aerated lagoon process do not meet any of the standards taken into account in our study (Algerian discharge standard "35 mg/L", WHO standard [26] "30 mg/L" and FAO standard [24] "70 mg/L"). On the other hand, the values recorded at the end of the two other processes, activated sludge and plants bed, fully comply with these three standards.

3.5. Nitrogen and Phosphorus Pollution

a. Nitrite

Figure 8 presents the seasonal variations of nitrite at the exit of the three stations between 2011 and 2020.

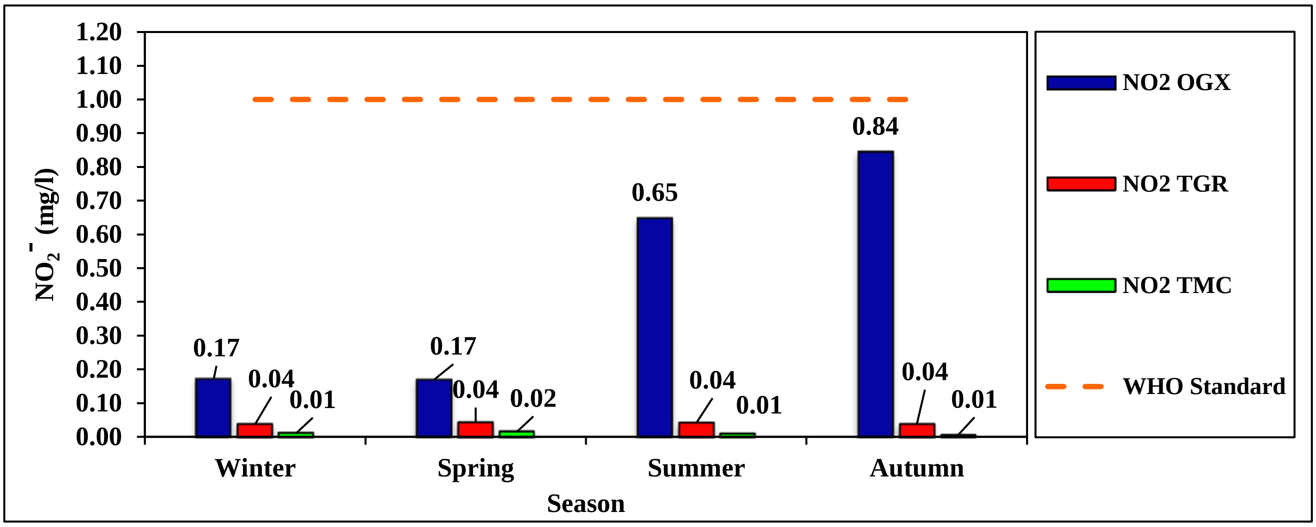

Figure 8. Values of nitrite recorded at the output of the stations of the three processes.

According to Figure 8, the maximum values are noted during the four seasons for the aerated lagoon and the minimum in the plants bed.

The difference between the average nitrite values of the seasons is significant in the aerated lagoon process. For the other two methods, this difference is almost absent. The maximum value of nitrite in Ouargla station is observed in autumn and the minimum in winter and spring.

With regard to water quality, the three processes examined produce treated wastewater with nitrite values lower than the value of the WHO standard [26] (1 mg/L).

b. Nitrate

Figure 9 shows the averages of the nitrite values at the exit of the three stations for each season.

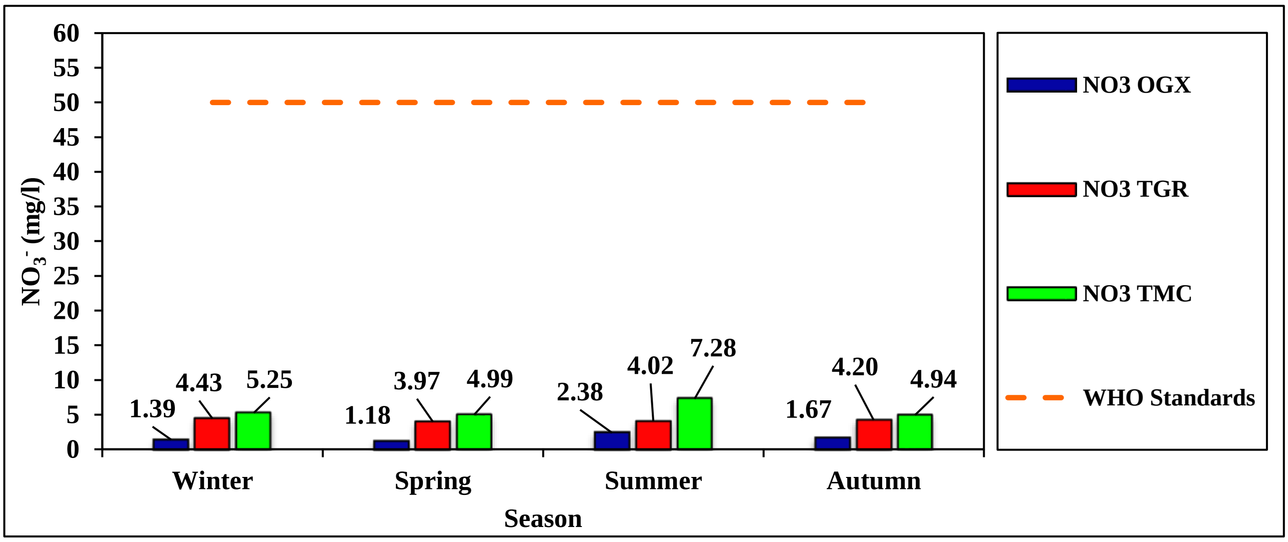

Figure 9. Values of nitrate recorded at the output of the stations of the three processes.

It is clearly observed in Figure 9 that the maximum values are recorded for the plants bed station and the minimum values in the aerated lagoon station.

This time and differently for nitrite, there is a stability of the values recorded during the four seasons for the activated sludge process and that of the aerated lagoon. For the plants bed process, the maximum value is noted during the summer and the minimum values during the fall and spring.

Compared to the WHO standard [26] (50 mg/L), the nitrate values of the treated wastewater from the three stations are below the value of the said standard.

c. Orthophosphate

Figure 10 summarizes the average values of orthophosphate during the four seasons for the three study methods.

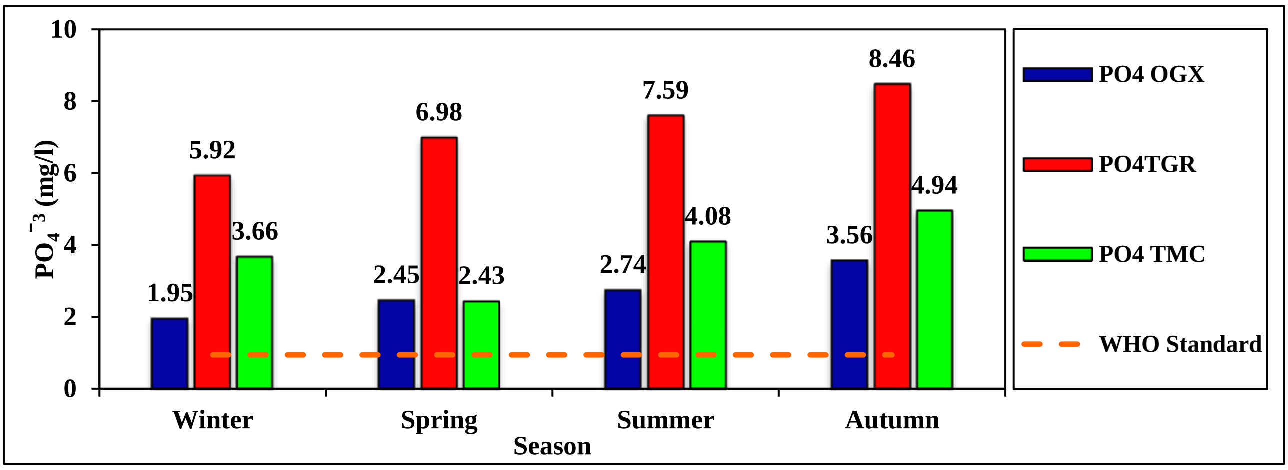

Figure 10. Values of orthophosphate recorded at the output of the stations of the three processes.

Figure 10 shows that the maximum average values of orthophosphate during the study period are observed for activated sludge and the minimum in the aerated lagoon station. Fall is the season that marked the maximum average orthophosphate values for the three processes.

Speaking of standards, the orthophosphate values of treated wastewater from the three processes are higher than those of the WHO standard [26] (0.94 mg/L).

4. General Discussion

4.1. Characteristics of the Raw Influent

The COD and BOD5 values recorded at the entrance of the three WWTPs fall within the range of reference values for raw domestic wastewater (BOD5 = 500 mg/L, COD = 1000 mg/L and SS = 600 mg/L [27]), with average COD/BOD_5 ratios of 2.6 for the AL process, 1.84 for the process AS and 1.50 for the PB process.

These ratios being less than two for the last two processes allow the conclusion that it is easily biodegradable raw wastewater [28–30] For the AL process, the ratio value is greater than 2.5 which indicates a slow decomposition and a high content of organic substances that are hardly decomposable or biologically indecomposable, which may be caused by a large proportion of industrial wastewater in municipal wastewater [30,31].

According to the results of analyses relating to raw wastewater, the average organic loading rates are: (i) 38% for the AL process, (ii) 65% for the AS process, and (iii) 48% for the PB process. These results show that the pollution loads received by the three WWTPs are lower than the nominal capacities of these WWTPs. These results show that the pollution loads received by the three WWTPs are lower than the nominal capacities of these WWTPs.

4.2. Physical (SS) and Biological (BOD_5, COD) Pollution Parameters

In general, these removal rates compared to those presented in other works [32–35] are very acceptable and reflect relative efficiency of the procedures adopted in study area.

Compared to work carried out before in the study areas, the purification removal rate values of BOD_5, COD and SS from the Ouargla station are lower than those determined by Bachi et al. [13] and recorded between 2011 and 2013. This is due to the several problems noted in the Ouargla stations, such as the failure of some aerators, hence the lack of oxygen diffused in the water and the formation of algae in the finishing basin which directly affects the concentration of SS at the exit.

According to the same authors, Bachi et al. [13], with the exception of BOD_5 which is stable, the treatment removal rate values recorded between 2011 and 2013 for COD and SS in the Témacine station were lower than those recorded between 2011 and 2018. The relative increase in purification efficiency is the result of the cleaning, development and rehabilitation works of the plants bed station after 2014.

For the activated sludge process, the comparison made between the removal rate values of our study and those of Bachi et al. [14] shows that there was an increase in the removal rate values of the three parameters compared to the values of 2012 and 2013. This increase in the performance of the activated sludge station was the consequence of maintenance and rehabilitation works on the station after 2014.

Regarding results of the exit values of BOD_5, COD, SS from the AL and PB systems of wastewater treatment, it is very well noted that there is a remarkable link between cited parameter values and air temperature. They increase as the air temperature increases and vice versa. This concurs with the opinion of Obaid et al. [36] about temperature effect on biological treatment of wastewater. They reported that temperature is considered the most challenging one in wastewater treatment methods. For the AS, our results agree with those of Von Sperling and de Lemos Chernicharo [37] who reported that there is less dependence on temperature as a result of higher technological input and mechanization levels.

According to Musy and Higy [38], Livingstone and Lotter [39], Preud'homme and Stefan [40], there is a positive correlation between air temperature and water temperature. When air temperature increases, water temperature increases, and when the water temperature increases, the concentration of dissolved oxygen (DO) decreases [41–44]. When DO decreases, aerobic bacteria activity decreases, and there is no degradation of organic matter which induces high concentrations of BOD_5, COD and SS at the exit of the systems [45].

In addition to air temperature, there is another important factor that affects DO which is wind [46,47]. This impact can be seen for the aerated lagoon system where values of BOD_5, COD and SS at the exit were very high compared to the two other processes because of aerator failures over the past few years which have caused a remarkable decrease in the oxygen diffused into the water.

For the Ouargla station, it should also be noted that in the absence of dissolved oxygen in recent years (successive breakdowns of aerators), the phosphorus trapped in the sediments can be released via complex chemical processes. Phosphorus then becomes available to aquatic plants which use the surpluses to proliferate, which leads to an increase in organic matter to decompose.

Compared to the different standards: Algerian [24], WHO [25] and FAO [26], and with the exception of the aerated lagoon process, the values of the parameters of physical and biological pollution of treated wastewater represent no risk to the environment and can be reused in agriculture.

4.3. Nitrogen Pollution

Nitrogen removal is one of the essential steps in wastewater treatment. Reactive nitrogen exists as NH_4^+ at typical wastewater pH values [48]. It is also a significant contaminant in domestic gray water and urine [49]. In wastewater, the nitrogen cycle goes through the different stages of biogeochemical evolution of the compound. It leads to the formation of nitrogen gas (dinitrogen N2), starting with organic nitrogen and passing through ammonia, nitrite and nitrate [50]. In our study, we focused on nitrites (NO_2^-) or nitrous nitrogen (unstable chemical form, dangerous for fish) and nitrates (NO_3^-) or nitric nitrogen (stable, soluble form, assimilable by plants or move freely in the ground.) [50–54].

In our study, we observed that there is no relationship between nitrite and air temperature, and maximal value was registered in autumn and not in summer. In fact, the micro-organisms responsible for nitrification: ammonia oxidizing bacteria (AOB) and nitrite oxidising bacteria (NOB) are fragile and require a constant water temperature (greater than or equal to 12 °C).

Compared to research of Bachi et al. [18,19] on station data between 2011 and 2013, the average values of nitrites and nitrates during the 8 years have the same tendencies: maximum values observed in the aerated lagoon process and minimum for the plants bed process for nitrite. For nitrate, it was the opposite, with maximum average values observed in the plants bed process and the minimum in the aerated lagoon.

Still comparing with the results of Bachi et al. [18,19], the average nitrite values for 8 years were low compared to the period between 2011 and 2013 for the three processes but with a big difference for the aerated lagoon process. For nitrate, the average values of 8 years at the end of the aerated lagoon system were higher than those of 2011–2013. On the other hand, for the plants bed process, the average values of the three years (2011–2013) were higher than those of 8 years (2011–2018).

Despite these variations in the values of nitrite and nitrate at the exit of the three stations and despite the values which sometimes exceed the values recorded at the entry for the aerated lagoon, it is very interesting to know that these values are lower than those of the WHO standard [25]; therefore, this treated wastewater poses no risk to the environment.

4.4. Phosphorus Pollution

Phosphorus in wastewater is derived from natural phosphorus sources and their use. It is multiple [55] (Villebrun, 1989). Wastewater phosphorus, particulate or soluble, essentially consists of: (i) inorganic phosphorus and orthophosphates which are phosphates that can be dosed without hydrolysis or digestion oxidizing; and (ii) organic phosphorus: phospholipids, esters, polynucleotides, etc. Total phosphorus is the sum of inorganic and organic phosphorus [56,57].

The results obtained in our studies showed that the maximum average values for the period from 2011 to 2018 were observed in the activated sludge station, while the minimum average values were in the aerated lagoon station.

Compared to the results of Bachi et al. [18,19], the average values for the period 2011–2013 were a bit low compared to those for the period 2011–2018 for the aerated lagoon. On the other hand, the opposite occurred in the activated sludge station where the values were important in 2011–2013.

Beforehand, it should be known that the quantity of sludge produced in the aerated lagoon station is low compared to that produced in the activated sludge station. This difference in quantity generates a difference in the concentration of total phosphorus (organic and inorganic) and consequently orthophosphate, especially since we know that in conventional activated sludge, the organic phosphorus content is of the order of 2% per gram of biomass; in dephosphating activated sludge, the organic phosphorus content can reach 8 to 10% per gram of biomass [57]. This explains the high concentrations of orthophosphate in the activated sludge system.

Compared to the value required by WHO [25], the average values of orthophosphate from the three stations are very high; consequently, the treated wastewater poses a risk to the environment.

5. Conclusions

Wastewater treatment not only protects the environment but also, depending on conditions, reuses it for irrigation. The choice of wastewater treatment process is based on several criteria, such as the quantity and quality of raw sewage, operating costs and climatic conditions.

Several studies have analyzed the wastewater treatment performance of biological processes without comparing these processes.

In our study, we compared the performance of three biological processes: aerated lagoon, activated sludge and constructed wetland in an arid climate.

The results showed that the treatment performance of the three biological processes during the 8 years of the study, exceeded 60% with an advantage for the activated sludge process, where the biological pollution elimination rates were around 90%. It also showed that the aerated lagoon process of the city of Ouargla lost this performance from one year to another because of the continuous breakdowns of the aerators.

Statistically speaking, there is a significant difference between the treatment performance of activated sludge and aerated lagoon processes. In the same context, the variability of pollution removal rates is significant for aerated lagoons.

For the quality of treated wastewater, the study showed that, with the exception of the aerated lagoon process, the physical and biological parameters analyzed at the outlet of the stations comply with the various standards (Algerian, WHO and FAO). It also showed that in the aerated lagoon plant, the concentrations of these pollution parameters are greatly influenced by the climate; they increase as the air temperature increases and vice versa.

In the case of the constructed wetland process, the results showed the effectiveness of this process but not for the activated sludge processes. However, the small amounts of pure water produced (14 m^3/day) and the need for constant maintenance of the facilities made this process unreliable.

Regarding the activated sludge process, the concentration values of the various pollution parameters are relatively stable and not influenced by the change of seasons.

As a final conclusion and based on what has been mentioned, the activated sludge process is the most suitable for the climatic conditions of the department of Ouargla.

Author Contributions: Conceptualization, O.E.B., M.T.H., S.B., N.A.-A., S.S., S.K. and H.M.N.; methodology, O.E.B., M.T.H., S.B., N.A.-A., S.S., S.K. and H.M.N.; software, O.E.B., M.T.H., S.B., N.A.-A., S.S., S.K. and H.M.N.; validation, O.E.B., M.T.H., S.B., N.A.-A., S.S., S.K. and H.M.N.; formal analysis, O.E.B., M.T.H., M.T.H., S.B., N.A.-A., S.S., S.K., H.M.N.; investigation, O.E.B., M.T.H., M.T.H., S.B., N.A.-A., S.S., S.K. and H.M.N.; resources, O.E.B., M.T.H., S.B., N.A.-A., S.S., S.K. and H.M.N.; data curation, O.E.B., M.T.H., S.B., N.A.-A., S.S., S.K. and H.M.N.; writing—original draft preparation, O.E.B., M.T.H., S.B., N.A.-A., S.S., S.K. and H.M.N.; writing—review and editing, O.E.B., M.T.H., S.B., N.A.-A., S.S., S.K. and H.M.N.; visualization, M.T.H.; supervision, M.T.H.; project administration, O.E.B., M.T.H., S.B., N.A.-A., S.S., S.K. and H.M.N.; funding acquisition, O.E.B., M.T.H., S.B., N.A.-A., S.S., S.K. and H.M.N. All authors have read and agreed to the published version of the manuscript.

Funding: This research work was funded by Department of Civil, Environmental and Natural Resources Engineering, Lulea University of Technology, SWEDEN.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data used to support the findings of this study are included within the article.

Acknowledgments: The authors extend their thanks to the Department of Civil, Environmental and Natural Resources Engineering, Lulea University of Technology, SWEDEN for partially funding this work.

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

References

1. Belksier, M.S.; Chaab, S.; Abour, F. Qualité hydro chimique des eaux de la nappe superficielle dans la région de l'Oued Righ et évaluation de sa vulnérabilité à la pollution. *Rev. Sci. Technol. Synth.* **2016**, *32*, 42–57.
2. Khechana, S.; Derradji, F.; Derouiche, A. La gestion intégrée des ressources en eau dans la vallée d'Oued-Souf (SE Algérien): Enjeux d'adaptation d'une nouvelle stratégie. *Rev. Sci. Fondam. Appl.* **2010**, *2*, 22–36.
3. Besbes, M.; Abdous, B.; Abidi, B.; Ayed, A.; Bachta, M.; Babasy, M.; Baccar, B.B.; el Batti, D.; Salah, Y.B.; Charreton, M.B.; et al. Système Aquifère du Sahara Septentrional, gestion commune d'un bassin transfrontière. *Houille Blanche* **2003**, *89*, 128–133. [CrossRef]
4. Idder, T.; Idder, A.; Cheloufi, H.; Benzida, A.; Khemis, R.; Moguedet, G. La surexploitation des ressources hydriques au Sahara algérien et ses conséquences sur l'environnement. Un cas typique: L'oasis de Ouargla (Sahara septentrional). *Tech. Sci. Méthodes* **2013**, *5*, 31–39. [CrossRef]
5. Sofiane, S.; Bachi, O.E.K.; Yamina, G. Etude de la Qualité Physico-chimique des Eaux de la Nappe Phréatique de la Région de Ouargla (Sahara Septentrional de L'Algérie). *Tunis. J. Med. Plants Nat. Prod.* **2013**, *9*, 44–48.
6. Idder, T. 2007. Le problème des excédents hydriques à Ouargla: Situation actuelle et perspectives d'amélioration. *Sécheresse* **2007**, *18*, 161–167.
7. Amiri, K.; Bekkari, N.; Débbakh, A.; Benmalek, A.; Bouchahm, N. Caractérisation des eaux usées des rejets domestiques de la ville de Touggourt (Algérie). *J. Algér. Rég. Arid.* **2017**, *14*, 104–108.
8. Bouznad, I.; Zouini, D.; Nouiri, I.; Khelfaoui, F. Essai de Modélisation de la Gestion des ressources en eau dans la vallée d'Oued Righ (Sahara septentrional algérien) par l'Utilisation d'un outil d'aide à la décision WEAP. *Rev. Sci. Technol. Synth.* **2016**, *33*, 56–71.
9. Saggaï, S.; Bachi, O.E.K.; Saggaï, A. Effect of quality of phreatic aquifer water and water upwelling on constructions. A case study of Ouargla. *AIP Conf. Proc.* **2016**, *1758*, 030026. [CrossRef]
10. Remini, B.; Kechad, R. Impact of the water table razing on the degradation of El Oued palm plantation (Algeria) mechanisms and solutions. *Geogr. Tech.* **2011**, *1*, 48–56.
11. Zajda, M.; Aleksander-Kwaterczak, U. Wastewater Treatment Methods for Effluents from the Confectionery Industry—An Overview. *J. Ecol. Eng.* **2019**, *20*, 293–304. [CrossRef]
12. Ahammad, S.Z.; Graham, D.W.; Dolfing, J. Encyclopedia of Environmental Management. In *Wastewater Treatment: Biological*; IWA Publishing: London, UK, 2013; pp. 2645–2656.
13. Rajasulochana, P.; Preethy, V. Comparison on efficiency of various techniques in treatment of waste and sewage water—A comprehensive review. *Resour. Effic. Technol.* **2016**, *2*, 175–184. [CrossRef]
14. Hernandez Leal, L.; Temmink, H.; Zeeman, G.; Buisman, C. Comparison of three systems for biological greywater treatment. *Water* **2010**, *2*, 155–169. [CrossRef]
15. Boutin, C. Eléments de comparaison techniques et économiques des filières d'épuration adaptées aux petites collectivités. *Ingénieries Eau. Agric. Territ.* **2003**, *34*, 47–55.
16. Jung, C.G.; Fontana, A.; Cretenot, D.; Belkhodja, M. Traitement des boues d'épuration: Comparaison entre les procédés par oxydation par voie humide et par incinération. *L'Eau L'industrie Les. Nuis.* **2002**, *249*, 49–53.
17. Kibi, N.; Sasseville, J.L.; Martel, J.M.; Blais, J.F. Choix multicritère de procédés d'épuration des eaux usées municipales. *Rev. Sci. L'eau/J. Water Sci.* **2000**, *13*, 21–38. [CrossRef]
18. Bachi, O.E.K.; Halilata, M.T.; Bissati, S. Etude comparative de deux techniques d'épuration des eaux usées sous un milieu aride (lagunage aéré et phyto-épuration) Cas de la wilaya de Ouargla. *Rev. BioRessour.* **2016**, *6*, 125–138. [CrossRef]
19. Bachi, O.E.K.; Halilata, M.T.; Bissati, S. Sewage in Algerian Oasis: Comparison of the purifying efficiency of two processes (WWTP and WWTAS). *Energy Procedia* **2015**, *74*, 752–759. [CrossRef]
20. De Martonne, E. Aréisme et Indice d'aridité. In *Comptes Rendus de L'Academy of Science*; Wikipedia: Paris, France, 1926; pp. 1395–1398.
21. Tradat, M.H. *Chimie Des Eaux*; Première, le Griffon D'argile Inc.: Sainte-Foy, QC, Canada, 1992; 537p.
22. Rejsek, F. *Analyse Des Eaux Aspects Réglementaires et Techniques*; CRDP: Aquitaine, France, 2002; 358p.

23. Clair, N.S.; Perry, L.M.; Gene, F.P. *Chemistry for Environmental Engineering and Science*, 5th ed.; McGraw-Hill Companies Inc.: New York, NY, USA, 2003; 233p.
24. FAO. *L'irrigation Avec Des Eaux Usées Traitées: Manuel D'utilisation*; University of Liège: Liège, Belgium, 2003; 73p.
25. JORA. Norms of the rejected treated wastewater. *Annex. Alger. Repub. Off. J.* **1993**, *46*, 7.
26. WHO. *Health Guidelines for the Use of Wastewater in Agriculture and Aquaculture*; Technical report, No. 778; World health Organization: Geneva, Switzerland, 1989.
27. JORA. Maximum limit values for substance content harmful effects of non-domestic wastewater when they are released into a network public sewer or in a wastewater treatment plant. *Annex. Alger. Repub. Off. J.* **2009**, *36*, 18.
28. Metcalf and Eddy, Inc. *Wastewater Engineering: Treatment, Disposal, and Reuse*, 3rd ed.; McGraw-Hill, Inc.: Singapore, 1991.
29. Ashley, R.; Hvitved-Jacobsen, T.; Krajewski, J.L.B. Quo vadis sewer process modeling? *Water Sci. Technol.* **1999**, *39*, 9–22. [CrossRef]
30. Klimiuk, E.; Łebkowska, M. *Biotechnologia w Ochronie Środowiska*; Wydawnictwo Naukowe PWN: Warszawa, Poland, 2008.
31. Ekama, G.A.; Wenzel, M.C. Denitrification kinetics in biological N and P removal acti-vated sludge systems treating municipal wastewater. *Water Sci. Technol.* **1999**, *39*, 69–77. [CrossRef]
32. Hamid, C.; El Watik, L.; Ramchoun, Y.; Fathallah, R.; Ayyach, A.; Fathallah, Z.; El Midaoui, A.; Hbaiz, E. Étude des performances épuratoires de la technique du lagunage aéré appliquée à la station d'épuration de la ville d'Errachidia—Maroc. *Afr. Sci.* **2014**, *10*, 173–183.
33. Maiga, A.H.; Konate, Y.; Wethe, J.; Denyigba, K.; Zoungrana, D.; Togola, L. Performances épuratoires d'une filière de trois bassins en série de lagunage à microphytes sous climat sahélien: Cas de la station de traitement des eaux usées de 21E (groupe EIER-ETSHER). *Rev. Sci. L'eau/J. Water Sci.* **2008**, *21*, 399–411. [CrossRef]
34. Hamaidi-Chergui, F.; Zoubiri, A.F.; Hamaidi, M.S.; Debib, A.; Kais, H. Evaluation de l'efficacité de la station d'épuration de Médéa (Algérie). *Larhyss J.* **2016**, *26*, 113–128.
35. Tahri, M.; Larif, M.; Quabli, H.; Taky, M.; Elamrani, M.; El Midaoui, A.; Benazouz, K.; Khimani, M. Étude et suivi des performances des traitements primaire et secondaire des eaux usées de la station d'épuration de Marrakech. *Eur. Sci. J.* **2015**, *11*, 139–154.
36. Obaid, H.A.; Shahid, S.; Basim, K.N.; Chelliapan, S. Modeling of wastewater quality in an urban area during festival and rainy days. *Water Sci. Technol.* **2015**, *72*, 1029–1042. [CrossRef]
37. Von Sperling, M.; de LemosChernicharo, C.A. *Biological Wastewater Treatment in Warm Climate Regions*; IWA Publishing: Padstow, UK, 2005; Volume II, pp. 839–1460.
38. Musy, A.; Higy, C. *Hydrologie: Une Science de la Nature*; PPUR Presses Polytechniques: Lausanne, Switzerland, 2004; 314p.
39. Livingstone, D.M.; Lotter, A.F. The relationship between air and water temperatures in lakes of the Swiss Plateau: A case study with palæolimnological implications. *J. Paleolimnol.* **1998**, *19*, 181–198. [CrossRef]
40. Preud'homme, E.B.; Stefan, H.G. *Relationship between Water Temperatures and Air Temperatures for Central, U.S. Streams*; Project Report No. 333. ST; Anthony Falls Hydraulic Laboratory, University of Minnesota: St. Paul, MI, USA, 1992.
41. Walczyńska, A.; Sobczyk, Ł. The underestimated role of temperature–oxygen relationship in large-scale studies on size to temperature response. *Ecol. Evol.* **2017**, *7*, 7434–7441. [CrossRef]
42. Harvey, R.; Lye, L.; Khan, A.; Paterson, R. The Influence of Air Temperature on Water Temperature and the Concentration of Dissolved Oxygen in Newfoundland Rivers. *Can. Water Resour. J.* **2011**, *36*, 171–192. [CrossRef]
43. Anonyme. La dynamique de la vie. L'eau support de la vie. L'oxygène de l'eau. Cahier indicateurs N° 1. Loire Estuaire Cellule de Mesures et de Bilans. 2002. Available online: https://www.loire-estuaire.org/upload/iedit/1/pj/43684_2860_CMB_206106_L2A1.pdf (accessed on 25 August 2022).
44. Moatar, F.; Poirel, A.; Obled, C. Analyse de séries temporelles de mesures de l'oxygène dissous et du pH sur la Loire au niveau du site nucléaire de Dampierre (Loiret): 1. Compréhension des variations temporelles des teneurs en oxygène dissous et du pH en relation avec des données hydrométéorologiques. *Hydroécol. Appl.* **1999**, *11*, 127–151.
45. Andreoni, V. Anaerobic Digestion of Swine Slurry and agro-industrial Wastes in fixed bed up–flow digesters. In Proceedings of the Symposium, Nice, France, 19–21 June 1989; pp. 4–6, Technical Advances in Biofilm Reactor.
46. Boyd, E.C.; Teichert-Coddington, D. Relationship between wind speed and reaeration in small aquaculture ponds. *Aquac. Eng.* **1992**, *11*, 121–131. [CrossRef]
47. Yu, S.L.; Hamrick, J.M.; Lee, D. Wind Effects on Air-Water Oxygen Transfer in a Lake. In *Gas Transfer at Water Surfaces*; Brutsaert, W., Jirka, G.H., Eds.; Water Science and Technology Library; Springer: Dordrecht, The Netherlands, 1984; Volume 2.
48. Sprynskyy, M.; Lebedynets, M.; Zbytniewski, R.; Namieśnik, J.; Buszewski, B. Ammonium removal from aqueous solution by natural zeolite, Transcarpathianmordenite, kinetics, equilibrium and column tests. *Sep. Purif. Technol.* **2005**, *46*, 155–160. [CrossRef]
49. Eriksson, E.; Auffarth, K.; Henze, M.; Ledin, A. Characteristics of grey wastewater. *Urban Water* **2002**, *4*, 85–104. [CrossRef]
50. Koller, E. *Traitement Des Pollutions Industrielles. Eau–Air–Déchêts–Sols–Boues*; Dunod: Paris, France, 2004; 424p.
51. Argilier, C.; Augeard, B.; Baudoin, J.M.; Poulain, P.B.; Beaujeu, G.; Bellier, J.; Benhassen, F.; Bolzan, D.; Bouligand, S.; Bourrain, X.; et al. *Guide Technique Relatif à L'évaluation de L'état Des Eaux de Surface Continentales (Cours D'eau, Canaux, Plans D'eau)*; L'Institut National de Recherche en Sciences et Technologies pour L'Environnement et L'Agriculture: Irstea, France, 2016; 106p.
52. CEAEQ. *Détermination Des Nitrates et Des Nitrites: Méthode Colorimétrique Automatisée Avec le Sulfate D'hydrazine et le N.E.D.*; MA. 300–NO3 2.0; Rév. 2 Centre d'Expertise en Analyse Environnementale du Québec; Ministère du Développement Durable, de l'Environnement et de la Lutte Contre Les Changements Climatiques: Quebec City, QC, Canada, 2014; 13p.

53. Deronzier, G.; Schétrite, S.; Racault, Y.; Canler, J.P.; Liénard, A.; Héduit, A.; Duchène, P. *Traitement de L'azote Dans Les Stations D'épuration Biologique Des Petites Collectivités: Le Document Technique FNDAE n° 25*; Cemagref Éditions: Grenoble, France, 2001; 79p.
54. Da-Riz, V.; Guillard, A.S. Nitrites et nitrates dans les produits alimentaires: Le point sur la normalisation. *Bull. Liaison CTSCCV* **2000**, *10*, 403–412.
55. Villebrun, J.F. La Déphosphatation Biologique Appliquée à la Station d'épuration de Craon. Rapport de la DDAF de la Mayenne. 1989.
56. CEAEQ. *Détermination Des Orthophosphates Dans L'eau: Méthode Colorimétrique Automatisée à L'acide Ascorbique*; MA. 303–P 1.1, Rév. 2; Centre d'Expertise en Analyse Environnementale du Québec, Ministère du Développement durable, de l'Environnement et de la Lutte Contre les Changements Climatiques: Quebec City, QC, Canada, 2016; 11p.
57. Deronzier, G.; Choubert, J.M. Traitement du phosphore dans les petites stations d'épuration à boues activées Comparaisons techniques et économiques des voies de traitement biologique et physico-chimique. FNDAE n° 29, 1er édition coordonnée par le Cemagref. *Doc. Tech. FNDAE* **2004**, 29. Available online: http://www.fndae.fr/documentation/PDF/Fndae29_a.pdf (accessed on 25 August 2022).