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Study the Effectiveness of the Natural Lagoons for Removal of Organic Matter, Nutrients and Fecal Coliform from Urban Domestic Wastewater under Arid Climate (Morocco)

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ABSTRACT

Morocco is one of the countries most affected by the scarcity of water resources and the poor distribution of rainfall. Natural lagoon is the most widely used treatment process in Morocco. Indeed, Morocco is a sunny country throughout the year. The lagoon system requires minimal effort in operation and maintenance. Moreover, this system is the best process for removing bacteria indicators. For these reasons, a study of the purification performance of natural lagoons during five years, located in Chichaoua region (Morocco) was carried out. The lagoon system was monitored for five years, with measurements taken every three months at the input and output of the system. It received a hydraulic loading rate (HLR) between 1171 and 2760 m^3 with an average of 2053 m^3/day. The obtained results show the removal of 37% of TSS, 63% of BOD_5, 60% of COD, 61% of NH_4^+, 37% of TP, and 6.5 log units of coliforms during the mentioned monitoring period. Thus, the effluent values do not always comply with the Moroccan water quality requirement for irrigation reuse. Additionally, the statistical analyses confirm the presence of a strong linear correlation between almost all variables in the lagoon output. Therefore, the performance efficiency of the lagoon in removing organic matter and nutrients was significantly ($p < 0.05$) dependent on the season. However, the fecal contamination was not significantly ($p > 0.05$) affected by the seasons in this study. At the end of this study a complementary treatment before the reuse of treated wastewater, was proposed.

Keywords: natural lagoons; urban domestic wastewater; organic matter, nutrients; fecal coliform.

INTRODUCTION

The water resources in Morocco are affected qualitatively through industrial activities [Benaddi et al., 2022a; Benaddi et al., 2022b] and quantitatively by human activities, agricultural and industrial activities focused on satisfying food demands have also increased [Chaoua et al. 2018; Mancosu et al. 2015]. The use of water resources is at an all-time high in arid and semi-arid countries, including Morocco, due to recent irregular rainfall patterns, frequent droughts, and other environmental factors, consequently, water is becoming a precious resource. The reuse of wastewater is a menace to public health, the environment, and ecological stability. Therefore, wastewater treatment is an urgent necessity to protect water resources and reduce the water shortage problem, and it is a viable option for agriculture in developing countries. Moroccan urban areas discharged 550 Mm^3 per year of wastewater volume, and only 45% was treated by 117 plants. Therefore, the goal is to reuse 325 Mm^3 of treated wastewater in irrigation in 2030 (Morocco ministry of agriculture). The natural lagoon is a viable solution for rural and urban communities, since it is an eco-friendly wastewater treatment technique [Laidia Zerkaoui et al., 2020]. It is good landscape integration and a low-cost treatment method that produces effluents of good quality and free of various pollutants. Furthermore, the lagoon is easy to operate and maintain compared to other treatment methods. Several studies have shown that the lagoon system effectively decreased the majority of wastewater contamination, including suspended particles, organic matter, and nutrients [Allaoui et al., 2016; Laidia Zerkaoui et al., 2020]. Additionally, the presence of fecal contamination in domestic wastewater, including fecal coliform, might cause serious environmental problems [Nacir et al., 2012]. The objective of this work was to examine the performance of a lagoon treatment plant located in the Chichaoua region (Morocco) for treating domestic wastewater for five years taking into account the Moroccan irrigation standards for reuse and to evaluate the seasonality effects on the performance of lagoon system under arid climate, then propose an appropriate complementary treatment.

MATERIAL AND METHODS

Study site

Sampling was done at the Chichaoua wastewater treatment plant located in central Morocco (313238N; 84558W) (Fig. 1). The WWTP has a capacity of 22,000 equivalent inhabitants. It operated under 2053 m^3/day. Natural lagoons are the raw water treatment method used in this study. The first step is screening, and then the ponds are arranged and operated in series, with anaerobic ponds preceding the facultative ponds, which then feed into several maturation ponds.

Sample collection and analyses

Water sampling was conducted at the input and output of natural lagoons during five years from 01/2017 to 01/2021 with one sample per three months. They are stored in sterile glass bottles for microbial and physicochemical analysis. The bottles were transported in a cooler at a temperature of 4 °C to the laboratory analysis. The physicochemical parameters measured in the laboratory were Temperature, pH, Turbidity, Electrical conductivity, and dissolved oxygen, which were measured using a HI 9829 multi-parameter probe (HANNA, Woonsocket, RI, USA). Total suspended solids (TSS) were determined after filtering a sample through a Millipore filter (0.45 μm) and drying the retained residue at 105 °C for 120 min (AFNOR-T90-105) [AFNOR, 1997]; COD was determined by digestion followed by colorimetric dichromate method (AFNOR-T90-101) (AFNOR, 1997); The biological oxygen demand (BOD_5) is determined according to the respirometry method T90-103 of AFNOR (1983). Total phosphorus (TP) was performed by molybdate and ascorbic acid method after potassium peroxydisulfate digestion (AFNOR-T90-023) (AFNOR, 1997). NH^{4+} was determined by the indophenol method (AFNOR-T90-015) [AFNOR, 1997]; fecal coliforms (FC) count was performed according to the AFNOR Standard NF EN ISO 9308-1 [AFNOR, 1997] in TTC Tegretol medium. The dishes were incubated at 44.5 °C for FC for a period of 24 h and then the number of forming colony units was calculated.

Statistical analyses

To visualize the effect of the season on the lagoon-treated water, the data were subjected to principal component analysis (PCA). Then, Pearson linear correlation was applied to show the correlations between several parameters at the output of the lagoon.

RESULTS AND DISCUSSION

Coefficient of biodegradability (COD/BOD_5)

The COD/BOD_5 ratio for raw wastewater varies between 1.67 to 3.42 with an average of 2.15. According to [Ouafae El Hachemi and Hassan Elhalouani Salgot, 2012], biodegradability coefficients are calculated by the COD/BOD_5 ratio and depend on the nature and origin of the wastewater which can be domestic or industrial, the COD/BOD_5 ratio for raw domestic wastewater is generally between 1.25 and 2.5 and can be more than 10 for industrial wastewater, which requires different treatments. It can be observed that the coefficient of biodegradability has been evaluated at 3.42 in this study. This result confirms the presence of industrial discharge connected to the domestic wastewater network.

In situ parameters

The performance of natural lagoons was monitored for five years from January 2017 to January 2021. Figure 2 showed the variation of pH, DO, Temperature and EC at the input and output of the studied system. The obtained results for dissolved oxygen (Fig. 2A) show that the extreme minimum and maximum values observed at the inlet of the station were between 0.1 mg/l and 0.22 mg/l with an average concentration of 0.16 mg/l, while those at the outlet range between 0 mg/l and 3.92 mg/l with an average concentration of 1.16 mg/l. The presence of dissolved oxygen positively affects the aerobic degradation reactions of organic matter and more generally the biological balance of the hydraulic media. The oxygen measured in

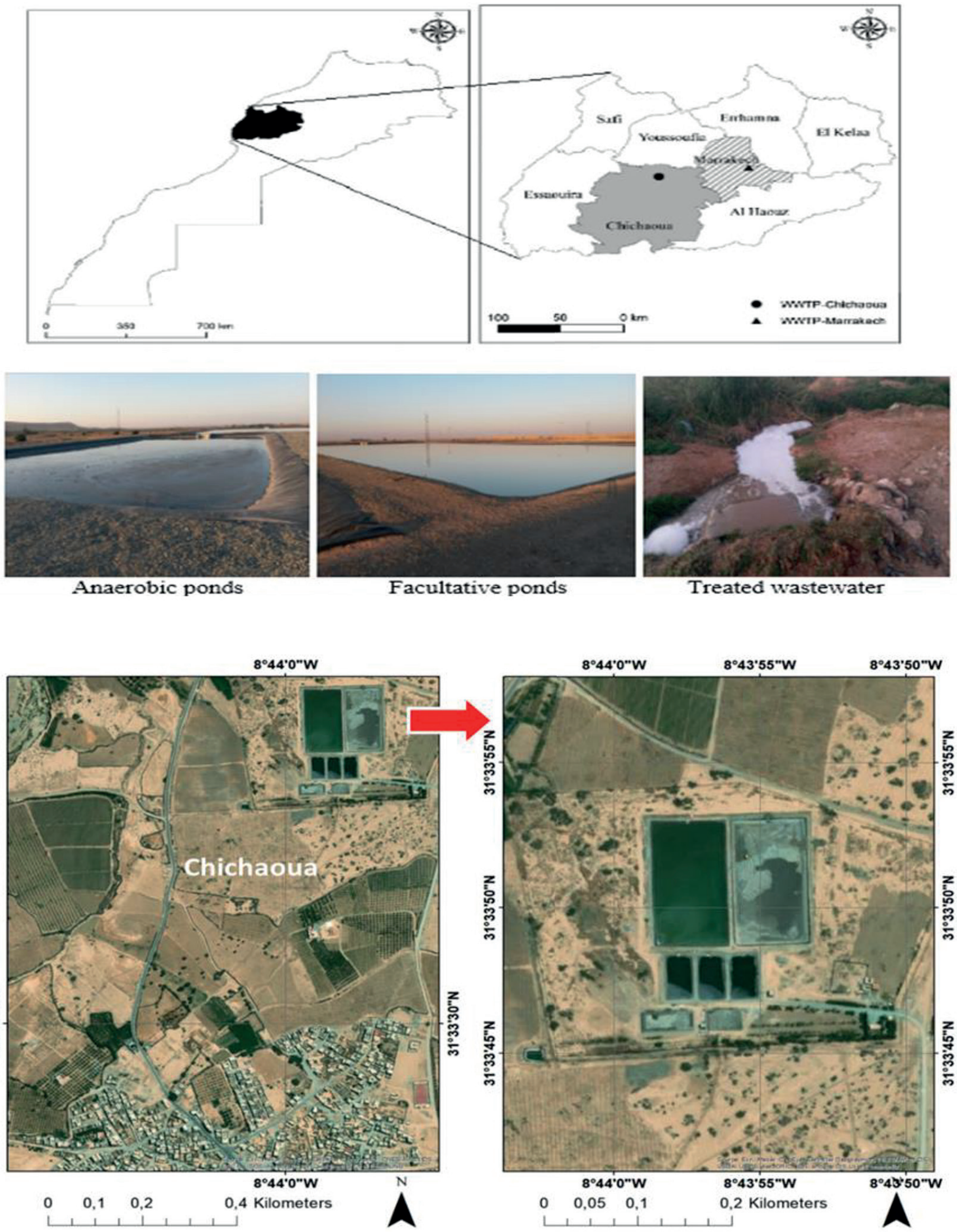

Figure 1. Localization geographic and photo of the lagoon wastewater treatment plant implemented at the Chichaoua (Morocco)

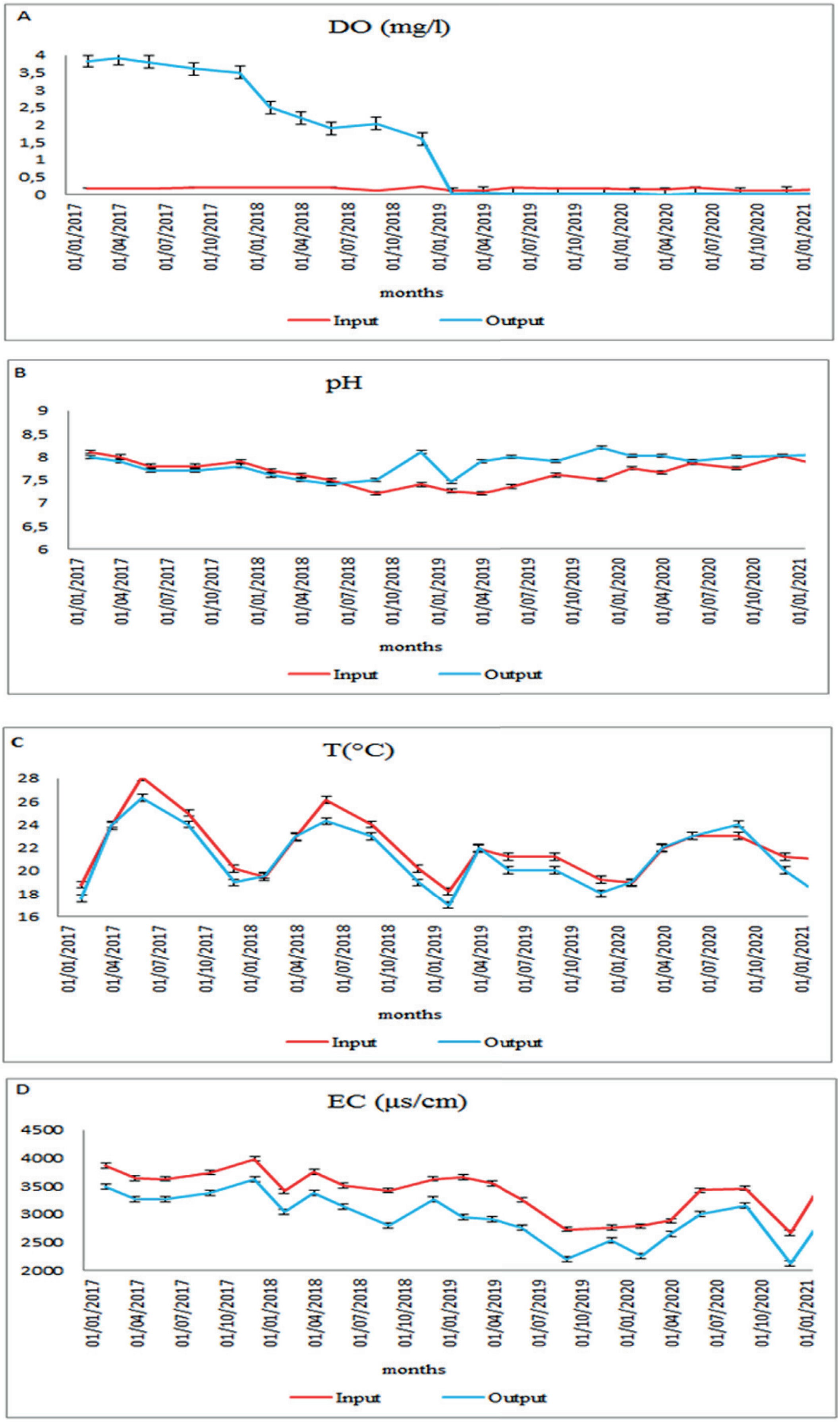

Figure 2. Evolution of the dissolved oxygen (mg/l), pH, temperature (°C) and electric conductivity (µS/cm) at the input and the output of the lagoon system

the basins is a result of plant and bacterial metabolism, as well as a transfer due to air diffusion. The lagoon-treated wastewater shows low DO concentrations from the midpoint to the end of the study. The decrease in DO could be due to the photosynthetic activities of the algae or the fall of dead tissue in the lagoons [Abdoulaye and Aboudou, 2016; Idrissi et al., 2015]. The pH value ranged from 7.05 to 8.5 and from 7.02 to 8.3 at the input and output of lagoons, respectively (Fig. 2B). [EL HACHEMI et al., 2012] reported that the variation in pH values is related to algal development. Thus, this element is responsible for the consumption of CO_2 dissolved in the water [Ouafae El Hachemi et al., 2012], and thus for the alkalinization of the water according to the following equation:

$$HCO_3^- + H^+ \rightarrow H_2CO_3 \rightarrow H_2O + CO_2 \qquad (1)$$

There is a slight increase in pH in the treated water, which can be explained by the nitrification reaction that releases H^+ ions [Ech-Chafay et al. 2020]. Additionally, the pH value was between (6.5 - 8.4) which is the admissible limit for wastewater reuse according to Moroccan Standards for reuse. The value of the wastewater temperature varied between 18.2 °C to 29.6 °C with an average of 21.53 °C, and for wastewater treated at the lagoon outlet was varied between 17 and 27.3 with an average of 21.08 (Fig. 2c). The difference between the input and output temperatures values was not statistically significant ($p < 0.05$). The conductivity of water directly indicates its salinity (United Nations Food and Agriculture Organization (FAO) 2003). It can be seen (Fig.2D) that the conductivity of the wastewater is high at the inlet of the lagoon (2597 to 4027 μs/cm), and a decrease is at the outlet of the lagoon (2126 to 3757 μS/cm), it is still lower than the admissible limit value for wastewater reuse, which is 12000 μS/cm (Moroccan Standards 2006) but higher than the admissible value recorded by FAO which is 700 μS/cm. The high conductivity values at the inlet of the WWTP are due to the salinity of the upstream drinking water. At the WWTP, the degradation of organic matter by bacteria contributes to the production of nutrient salts, such as nitrogen and phosphate; these results are reflected in the increase of conductivity. As a result of the assimilation of these salts by the algae, there could be a reduction of conductivity at the outlet of the lagoon.

Removal of organic pollution

The concentration of TSS in the wastewater varied between 246 and 484 with an average of 351.79 mg/l. Furthermore, TSS output ranged between 124 and 387 mg/l with TSS removal efficiency of 60% with an average of 37%. The reduction of TSS concentration in the lagoon is due to the sedimentation of the wastewater in the lagoons [Boutayeb and Bouzidi 2013] but the value of TSS in the treated wastewater is above the required standard of FAO (20 mg/l) and Morocco admissible for wastewater reuse (100 mg/l). This may be due to the presence of algae in the treated water [Chachoua et al., 2013]. The BOD_5 value is an indication of the amount of oxygen that is used for the destruction of decomposable organic matter by biochemical processes [Türker Okaygün,and Almaqadma, 2009]. The BOD_5 concentrations at the inlet range from 360 mg O_2/l to 780 mg/l with an average of 535.29 mg O_2/l (Figure 3B), those at the outlet range from 15.8 mg O_2/l to 400 mg O_2/l with an average of 184.82 mg O_2/l. The average COD concentration varies between 310 and 1075 mg/l at the output and the removal efficiency reaches 69% (Fig. 3C). The BOD_5 yields are higher than the COD yields, since the natural lagoon treatment system considerably reduces the biodegradable part of the effluent [Boutayeb and Bouzidi, 2013].

Nitrogen and phosphorus removal

According to Figure 4, the concentration of ammonium at the input of the lagoon is varied between 105.12 and 348.89 mg/l with an average of 192.51 mg/l, for the output, it ranged between 19.73 and 108 mg/l with 72.15 mg/l. This result indicates a degradation of ammonium concentrations up to 61%. The presence of algae in the basins provides a support for the growth of bacterial communities, thus providing the formation of a biofilm that contributes to the degradation of pollutants. Additionally, development of nitrifying bacteria, which are responsible for the nitrification of ammonium under aeration condition [Boutayeb and Bouzidi, 2013]. The ammonium removal was decreased from 86% in 2017 to 43% in 2021; this result can be due to the lower nitrification process over time. However, the average concentration of nitrate was 2.4 mg/l during 2017

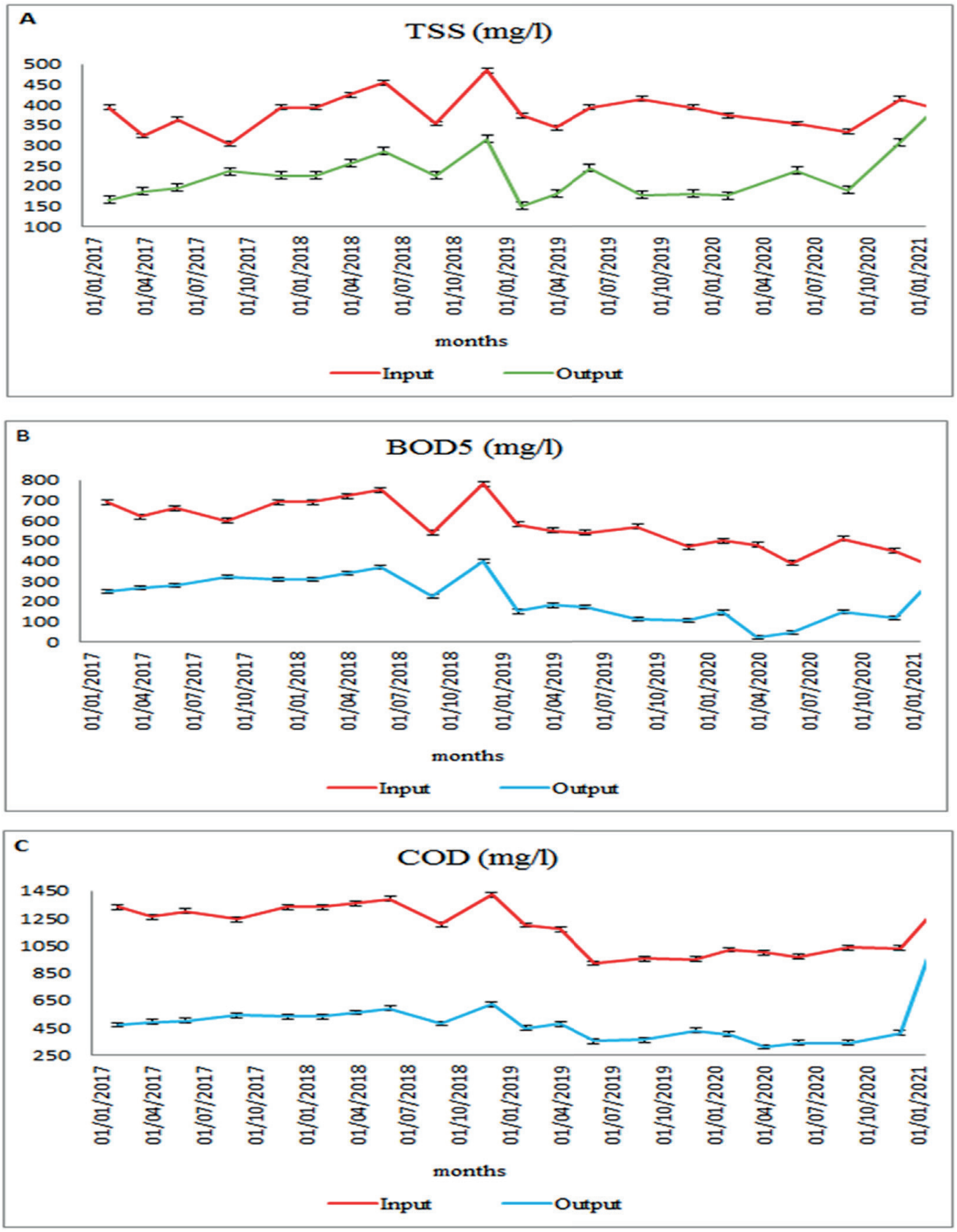

Figure 3. Evolution of the TTS (mg/l), BOD_5 (mg/l) and COD (mg/l) at the input and the output of the lagoon system

and 0.82 mg/l during 2021. [M. Driche, 2010] reported that the nitrates formed by the nitrification process diffused into the lower layers, where they transformed into nitrogen gazes (N_2) later by denitrification processes. The removal efficiency of TP ranged between 15 and 59% with an average of 37%. Usually, polyphosphates undergo hydrolysis and are converted to orthophosphate form; this process is usually very slow [Lenntech, 2015]. The organic phosphates constantly disappear in sediments; they are trapped in an insoluble form of precipitate [Pycha and Lopez, 2015]. Simultaneously, inorganic phosphorus is easily consumed by aquatic organisms. Some organisms are capable of storing the excess of phosphorus in the form of polyphosphates for future use [Gratziou and Chalatsi, 2017; Pycha and Lopez, 2015]. Under alkaline pH conditions with the presence of calcium, the removal of TP can be due to the precipitation of calcium [Moltó et al., 1991].

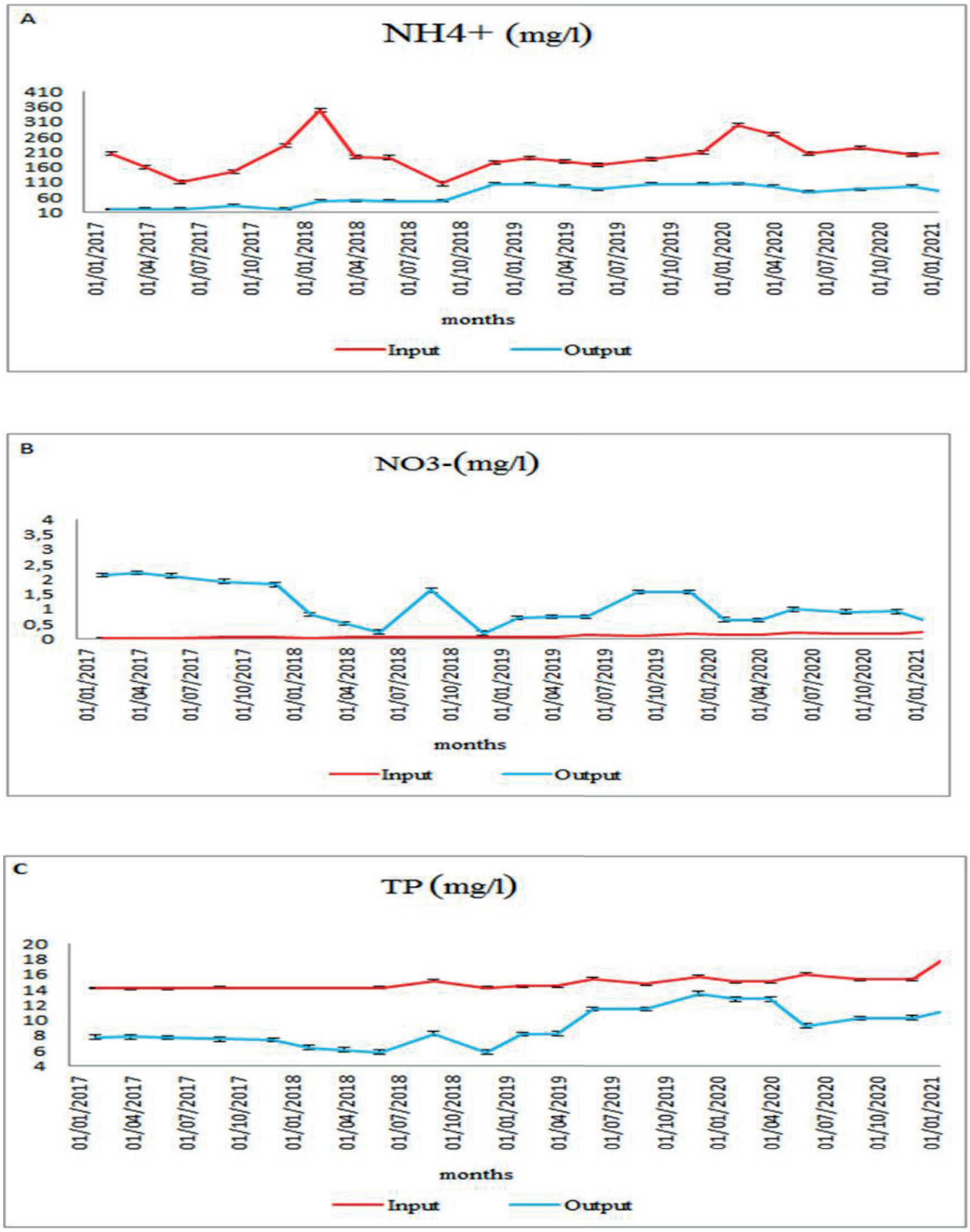

Figure 4. Evolution of the NH^{4+} (mg/l), NO^{3-} (mg/l) and TP (mg/l) at the input and the output of the lagoon system

Removal of fecal contamination

The results of the bacteriological analyses at the input of the treatment plant revealed the presence of fecal contamination. According to Figure 5, fecal coliforms varied between $2.2 \cdot 10^6$ and $5.9 \cdot 10^6$ CFU/100 ml with an average of $3.6 \cdot 10^6$ CFU/100 ml at the input. In turn, fecal coliforms varied between 10^5 and $4.5 \cdot 10^5$ CFU/100 ml with an average of $3.4 \cdot 10^5$ CFU/100 ml at the output of the lagoon system. The reduction of indicator bacteria can be due to various physico-chemical and/or biological processes, namely infiltration by sedimentation; competition with native species, predation by bacteriophage species (zooplankton), production of natural inhibiting or bactericidal substances (e.g. antibiotics) by certain bacteria and micro-algae, leading to the death of or a reduction in the reproduction of indicator germs [Ndip et al., 2008; Zidan et al., 2022]. However, the lagoon treatment adopted exceeds the values destined for irrigation (1000 CFU/100 ml).

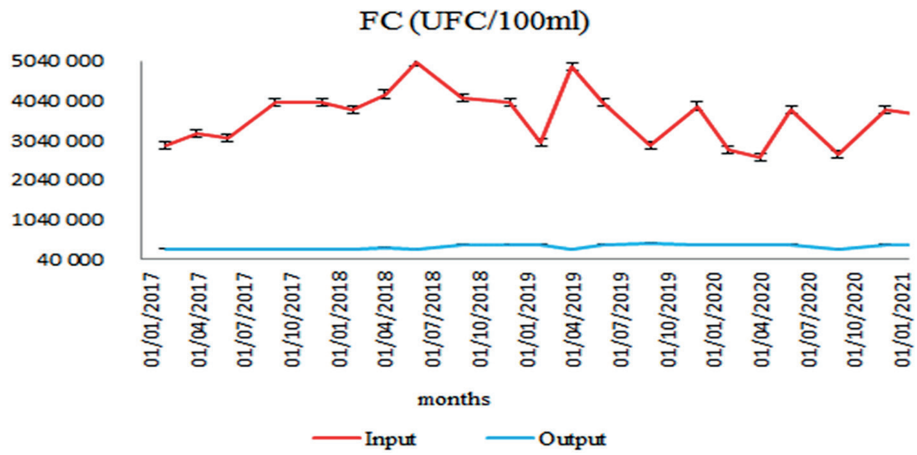

Figure 5. Evolution of the fecal coliform at the input and the output of the lagoon system

Correlation between physicochemical parameters and bacteriology

Figure 6 presents graphically the linear relationships between 8 parameters of the water qualities in the output of the lagoon systems. The correlations were based on 25 measurements for each parameter; the measurements were monitored during a five-year experiment. For BOD_5, a positive correlation was found with COD concentration but negatively with DO, NH_4^+, and TP at the output of the lagoon system. [Guemmaz and Neffar, 2019] reported that the multiplication and activity of microorganisms require DO for the degradation of organic matter. The availability of organic matter can affect the removal of TN in wastewater treatment processes [Stevik et al. 2004]. TN removal rate is strongly influenced by the organic load [Gajewska et al., 2014]. Nonetheless, Figure 6 shows a significant linear correlation ($p < .05$) between FC, NH_4^+, and TP in the outlet of the lagoon system. The nutrient has been shown to increase the survival and growth of bacteria [Boutilier et al., 2009; Van der Steen et al., 2000]. In addition, nutrients are known to be metabolic sources for microorganisms [Wu et al., 2016; Gatta et al. 2016] hypothesized that microorganisms could use chemotaxis to follow nutrient sources in water, or that

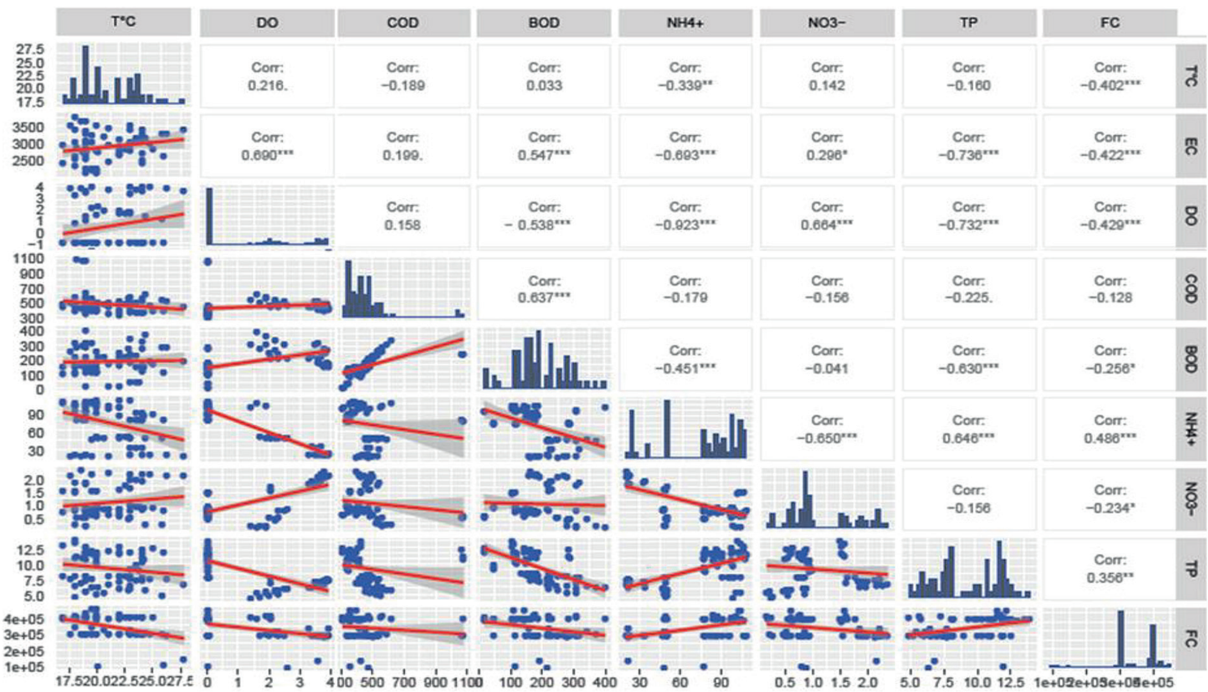

Figure 6. Scatter-plot matrix among parameter concentrations based on 25 samples collected during the experimental period (T in °C, FC in CFU/100 ml and all other units in mg/l)

they could survive longer and reproduce faster in the presence of available nitrogen. Furthermore, FC showed a negative correlation with temperature (r = 0.67*) and DO; the obtained results suggest that Temperature and dissolved oxygen value help to improve the capacity of the lagoon system to reduce coliform contamination. The temperature was generally acknowledged to be a critical factor influencing coliform removal in wastewater treatment methods [Stevik et al., 2004; Zidan et al., 2022]. The negative correlation between the values of DO and log bacteria concentrations in treated water suggests that aerobic unsaturated conditions might be more suitable for higher bacteria removal in the lagoon system. The effect of DO might involve the survival of the microorganisms inside the lagoon system. The improved aeration would provide better conditions for predator communities. Similarly, [Fernandez-Sarabia et al., 1992] noted significant correlations between DO concentration and bacterial die-off in the aquatic environment. The results of this study reported an 8–10 fold increase in bacterial die-off rate for coliforms and Clostridium sp. in response to short aeration treatment (2 h/ day) in a stabilization pond wastewater treatment plant [Fernandez-Sarabia et al., 1992]. Nonetheless, DO show a strong positive correlation with NH_4^+ and a negative with NO_3^- at the output of the lagoon. The oxygenation condition improved the oxidation of ammonium to nitrate by nitrifying bacteria; however, nitrate can reduce to nitrogen gas through heterotrophic denitrifiers under low oxygenation conditions [Zekker et al., 2019]. Finally, there were significant linear relationships between NH_4^+, and TP, which can be attributed to the high efficiency of the lagoon unit to reduce nutrients from wastewater, Therefore, the Algae can assimilate nutrients from wastewater into their biomass under photosynthetic activity [Delgadillo-Mirquez et al., 2016; Jia and Yuan 2016; Park and Craggs, 2011].

Effect of season period on the treated water

Principal component analysis (PCA) was realized to study the impact of seasons on the water quality at the output of the lagoon by grouping individuals based on the study parameters dataset (Fig.7). The first dimensions represent 39.3% of the total variability dataset combined with the

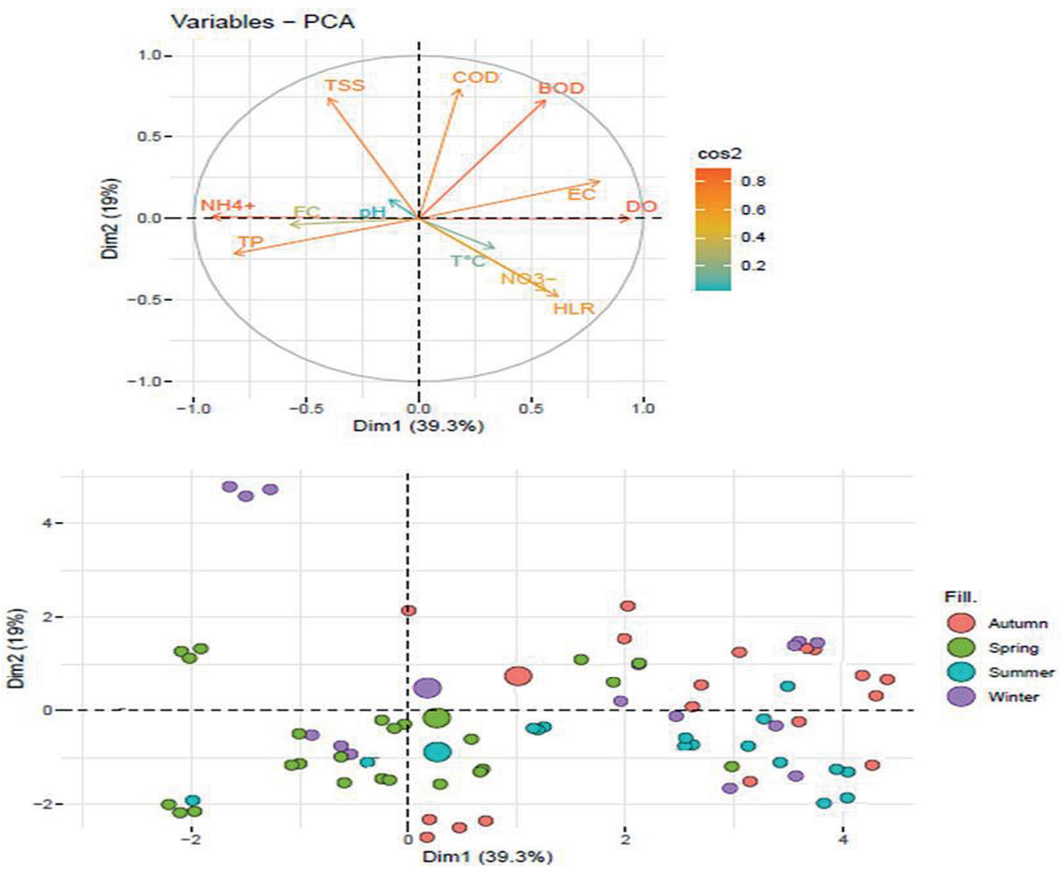

Figure 7. ACP results on season period on the treated water

second dimensions; they account 58.3% of the water quality variability [Dim 1 (39.3%) and Dim 2 (19%)]. The EC, DO, pH, BOD_5, NH_4^+, TP, FC, and HLR variables contributed to Dim 1. Nonetheless, there was no significant ($p < 0.05$) relationship with Dim2. Furthermore, the cos value of DO, EC, BOD_5, NH_4^+, and TP was higher (cos > 0.75) than other variables, Additionally, EC, DO and BOD_5 variables have a positive contribution to Dim1 during the autumn and summer seasons (cos > 0.75). A slight increase in DO concentration during the summer and autumn was due to the phenomenon of photosynthesis that intensified during this period, which causes an increase in the DO concentration by the lagoon [M. Ouhmidou et al., 2015; Benzha et al. 2015]. Indeed, other authors have noted that the increase in the BOD_5 concentration at the plant output in summer could be due to the growth of the algal biomass [Abis and Ceng 2004; Ouafae El Hachemi et al., 2012]. The NH^{4+} and TP output negatively contributed to Dim 1 and there is a negative effect of the two seasons (autumn and summer). These results can be attributed to the high seasonal impacts on the removal of TP and NH^{4+}, which indicates that the processes involved in the removal of these pollutants are likely seasonal. Additionally, ammonium and TP are preferentially absorbed when the algae simultaneously have NH_4^+ and TP [Delgadillo-Mirquez et al. 2016; Jia and Yuan 2016; Park and Craggs 2011], which explains the low concentrations measured in summer, without ignoring the part of nitrification and precipitation due to the high oxygen concentration of the environment [Ouhmidou et al. 2015]. The TSS contributes positively to Dim 2 (cos > 0.75), but there is a significant negative relationship with the four individuals during the summer and a negligible contribution with Dim 1 and Dim 2 (Fig. 7). This result is due to the TSS concentration in domestic wastewater during this period.

At the output of the lagoon, the oxygenation condition improved the oxidation of ammonium to nitrate by nitrifying bacteria; however, nitrate can reduce to nitrogen gas through heterotrophic denitrifiers under low oxygenation conditions [Zekker et al. 2019]. Finally, there were significant linear dependencies between NH_4^+, and TP, which can be attributed to the high efficiency of the lagoon unit to reduce nutrients from wastewater, Hence, the algae can assimilate nutrients from wastewater into their biomass under photosynthetic activity [Delgadillo-Mirquez et al. 2016; Jia and Yuan 2016; Park and Craggs 2011].

The proposed complementary treatment

The WWTP treats wastewater up to the secondary level; then the purified wastewater is discharged at a Oued. Along this Oued, this water can be reused anarchically by farmers, who can pump it from the river to irrigate their fields. Therefore, the quality of the water currently produced requires additional treatment for reuse in the irrigation of category crops, called "C", i.e., cereals, fodder, pastures and tree plantations. Just downstream of the pressurizing station a collective filtration station will be set up to further reduce organic matter and the installation of an UV disinfection device to ensure quality water for use in drip irrigation notably bacteriological parameters.

CONCLUSIONS

The performance efficiency of the lagoon natural for treating urban domestic wastewater was evaluated in a small urban community for five years under arid climatic conditions. The findings of this study have drawn the following conclusions:

1. Effectiveness of the lagoon system in the removal of organic matter, nutrient, and fecal contamination was; 37% of TSS, 63% of BOD_5, 60% of COD, 61% of NH_4^+, 37% of TP, and 6.5 log units of coliforms during four years of monitoring.
2. Season period significantly ($p < 0.05$) affected the removal of organic matter and nutrients in comparison with fecal coliforms content, which were unaffected by season change.
3. The quality of the treated wastewater does not always comply with the Moroccan norms of reuse of the effluents. Indeed, additional treatment is proposed for the reuse of wastewater treated by this system, consisting of a collective filtration station and a UV disinfection device.

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