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# The interaction of physicochemical and biological parameters in the maturation ponds in Tunisia

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ABSTRACT

Korba's wastewater treatment plant is a conventional activated sludge, followed by three maturation ponds in series. During this study, pH, temperature, dissolved oxygen (DO), chemical oxygen demand, biochemical oxygen demand, suspended solid, and fecal bacteria were monitored.The interactions between the physicochemical and biological parameters involved in the natural disinfection process are presented and discussed. *In situ* analyses were also conducted to study the seasonal variation of phytoplankton, zooplankton, and daily fluctuations of physicochemical parameters. This work shows the efficiency of the maturation ponds to improve the quality of treated water from existing activated sludge treatment plants. Light has a main role in the removal of feacal coliform in maturation ponds. It has a synergistic effect with pH, DO and temperature in the ponds. Regarding the influence of the operating conditions on the decay of *Escherichia coli* and streptococci in the ponds, a predominance of high pH, DO, and temperature was observed. The results show a direct relationship between DO increase and pH. Improving abiotic conditions in the spring (rise in temperature, photoperiod, and light intensity) and the presence of nutrients in summer promote more algal diversity and density of Cyanobacteria (*Oscillatoria*), chlorophyceae (*Chlamydomonas* sp.), Euglenophyceae (*phacus*), and Diatoms (*Cyclotella*).

*Keywords:* Removal bacteria; BOD; COD; Maturation ponds; pH; Phytoplankton; Zooplankton

## 1. Introduction

Wastewater stabilization ponds (WWSP) have long been considered as a good choice for wastewater treatment, mainly in developing countries and particularly under warm climate. The WWSP is a low-cost and ecological technology. It is effective, inexpensive, and easily operated [1], as well as having the ability to remove organic matter, nutrients, and coliforms [2]. However, depending on the characteristics of the influent and the operating conditions, the treated effluent may still contain ammonia, coliforms, biochemical oxygen demand (BOD), and other suspended solids (SSs) [3]. The final effluent often contains significant concentrations of algae that represent a significant proportion of the total BOD and SSs in the effluent [4].

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The main performance of maturation ponds, in most parts of the world, is the removal of pathogenic organisms [5,6]. In any case, maturation ponds can provide further removal of organic matter (BOD), achieve high ammonia removal, and produce effluents with an excellent quality, as long as they are properly designed [7]. Such ponds allow the interaction of the various physical and chemical factors, i.e. temperature, sunlight, pH, dissolved oxygen (DO), algal biomass, bacteriophage, nutrients, and predation [8], which contribute to the removal of pathogenic organisms. The bacteria oxidize organic matter, while algae assimilate mineral nutrients and provide oxygen for the bacteria. Thus, treatment is powered by sunlight via algal photosynthesis. The optical characteristics influencing sunlight exposure are fundamental in WWSP [9].

It has been recognized that a range of naturally occurring, complex interactions between bacteria, algae, protists, and metazoan zooplankton contribute greatly to effective wastewater treatment in WWSP [10]. Zooplankton plays an essential part in the recycling of algal primary productivity and in the stabilization of various organic materials within WWSP by feeding on phytoplankton and detrital seston and subsequently promoting the flocculation and sedimentation of particulate BOD and SSs within fecal pellets [11]. Smaller zooplankton such as rotifers have also been cited as playing an important role in shaping the ecology of certain lower forms of WWSP organisms (i.e. bacteria, small phytoplankton, and protozoa), thereby influencing the temporal succession of predominating planktonic species in such environments [12].

The penetration of sunlight in water favors the elimination of bacteria by disinfection [13]. Sunlight UV is the most important driver of WWSP disinfection, it interacts with other factors such as DO and pH [14]. Temperature, pH, and light intensity control the abundance and the activity of specific groups of micro-organisms. The water pH interferes in the phytoplankton metabolism, mainly due to the bioavailability of $CO_2$ for photosynthesis [15]. The diurnal pH change in the ponds is usually the result of algal uptake of $CO_2$ via photosynthesis; and the increase of $CO_2$ during the night is due to bacteria and algae respiration. The increase of pH up to 11 is common in WWSP, particularly during late afternoon [16].

The objective of this paper is to present the performance of a series of three maturation ponds which improve the sanitary quality of treated wastewater before reuse. These ponds are connected to the Korba activated sludge wastewater treatment plant. The interactions between the physicochemical and biological parameters involved in the natural disinfection process are presented and discussed.

## 2. Material and methods

### 2.1. Maturation ponds

Korba's wastewater treatment plant (Fig. 1) is a conventional activated sludge, followed by three maturation ponds in series acting as a tertiary treatment (MP1, MP2, and MP3). Treated effluent is essentially used for artificial recharge of the Korba aquifer; the rest is discharged into the Korba lagoon to maintain its ecological equilibrium. The average flow treated by maturation ponds is about 3,300 $m^3/d$. The maturation ponds characteristics are given in Table 1.

Samples were taken monthly from the inlet and outlet of the activated sludge unit and the inlet and outlet of each maturation pond between February 2008 and April 2009. Some *in situ* analyses were conducted to study the seasonal variation of phytoplankton and zooplankton biomass and diurnal fluctuations of physicochemical parameters.

### 2.2. Analytical methods

Physical-chemical and biological analyses were performed: pH, temperature, DO, chemical oxygen demand (COD), BOD, SS, and coliforms. DO and pH were monitored using WTW model 197i. Temperature was measured using a probe integrated in the pH meter. All analyses were taken according to Standard Methods [17]. The quantitative analysis of the phytoplankton biomass was made using the Uthermol method [18]. Continuous records of temperature, pH, and DO over 4–5 d in maturation ponds during April and September were collected with a multiparameter probe (YSI 6920).

## 3. Results and discussion

Table 2 summarizes the quality of the effluent treated by the Korba activated sludge wastewater treatment plant. It shows the removal efficiencies of 69, 46, and 57% for the TSS, COD, and $BOD_5$, respectively. The efficiency for total coliform (TC), fecal coliform (FC), *Escherichia coli*, and fecal streptococcus (FS) removal by the activated sludge is about 0.51, 0.88, 0.77, and 0.65 log unit, respectively. The activated sludges remove SSs and organic pollution, but it remains insufficient for fecal bacteria removal. This technology (activated sludge) does not meet the WHO [19] guidelines for agriculture reuse. Therefore, tertiary treatment is required before reuse.

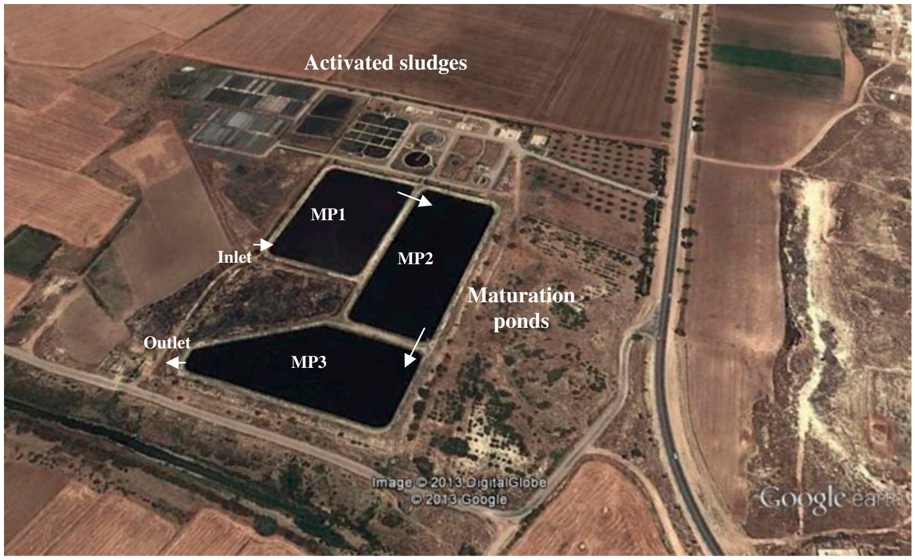


Fig. 1. View of Korba wastewater treatment plant with maturation ponds (36˚39´36.41´´N, 10˚54´24.22´´E; Google, June 2013).

Table 1
Characteristics of the maturation ponds

| Ponds | MP1 | MP2 | MP3 |
|---|---|---|---|
| Water depth (m) | 1 | 1 | 1 |
| Volume ($m^3$) | 8,116 | 8,675 | 9,411 |
| Residence time (d) | 2.46 | 2.63 | 2.85 |

### 3.1. pH, oxygen and temperature

Fig. 2 shows pH, temperature, and DO values during the monitoring periods. The wastewater temperature depends on the season. The winter period is the coldest period ($13 < T < 16$°C). During the spring period, the temperature of water increased and reached 22°C. Highest temperature ($30 < T < 35$°C) was measured in the summer.

Throughout the monitoring periods, the trend of pH in maturation ponds is alkaline. The pH at the inlet of the WWTP averaged 7.5, increasing to 8.5 at the outlet of MP3. The pH values increased from May to October and reached 9.63 during September. DO concentration increased from the inlet to the outlet of the WWTP. From November to March, the DO concentration did not exceed 3.5 mg/l. It increased in the spring season reaching 6–7 mg/l in summer. The highest DO concentration (12.5 mg/l) was measured in September. This value seems to be linked to the high pH and high temperature.

Fig. 3 shows that the peaks in the diurnal variations of temperature, pH, and DO observed in the maturation ponds occurred during the day. DO variations are followed by the temperature and pH. This was expected because water oxygenation is linked to algae activity under solar irradiance. The concentration of DO on the top water layer of the maturation pond can exceed 30 mg/l. During the peak of the algae activity, the pH can reach and exceed 9. The DO in the ponds was followed by an increase in the pH probably due to the increase in hydroxyl ions. The variation of DO and dissolved carbon dioxide indicated an alternating process. These results are in agreement with those obtained by Kayombo et al. [16] and Maïga et al. [20]. They found that the measured parameters in each pond were high showing the dependence on sunlight intensity. The variation of the parameters is governed by light intensity; and these results demonstrate that the gradual rise in pH during the morning and afternoon was accompanied by high DO production and dissolved carbon dioxide consumption.

### 3.2. SS, COD, and BOD removal

Fig. 4 shows that the activated sludge unit is primarily responsible for the removal of organic matter and SSs with average removal of 69, 46, and 57% for SS, COD, and BOD, respectively. At the outlet of the activated sludge treatment plant, all these parameters exceed the Tunisian guidelines TN.106.002 (1989) (COD 90, BDO 30 and SS 30 mg/l) for the discharge in the aquatic environment.

Table 2
Characterization of the raw and the treated effluent by the activated sludge plant

| Parameters/value | Raw water | | | | Decanted water | | | | Efficiency |
|---|---|---|---|---|---|---|---|---|---|
| | Min | Mean | Max | Standard deviation | Min | Mean | Max | Standard deviation | |
| Dissolved oxygene (mg/l) | 0.2 | 1 | 1.6 | 0.51 | 0.4 | 1.23 | 2.9 | 0.64 | |
| pH | 6.92 | 7.48 | 8.55 | 0.38 | 7.15 | 7.88 | 8.78 | 0.52 | |
| Temperature (°C) | 16.4 | 23.09 | 36 | 7.15 | 16 | 21.55 | 30.9 | 6.08 | |
| SS (mg/l) | 146 | 220 | 300 | 85.92 | 45 | 68 | 120 | 34.64 | 69.09 |
| COD (mg $O_2$/l) | 750 | 1,118 | 1,707 | 498.49 | 440 | 600 | 841 | 79.26 | 46.33 |
| $BO_5D$ (mg $O_2$/l) | 220 | 362 | 682 | 199.39 | 102 | 156 | 196 | 53.59 | 56.91 |
| TC/100 ml | 1.50E+06 | 9.46E+06 | 4.50E+07 | 1.27E+07 | 1.50E+06 | 3.67E+06 | 9.50E+06 | 2.60E+06 | 0.52 |
| FC/100 ml | 1.50E+06 | 5.12E+06 | 2.50E+07 | 6.24E+06 | 2.50E+05 | 6.54E+05 | 4.50E+06 | 1.10E+05 | 0.88 |
| *E. coli*/100 ml | 1.00E+06 | 2.45E+06 | 5.00E+06 | 1.53E+06 | 5.50E+05 | 3.69E+05 | 4.50E+06 | 3.82E+05 | 0.77 |
| FS/100 ml | 4.50E+05 | 1.48E+06 | 4.50E+06 | 1.57E+06 | 1.50E+05 | 3.81E+05 | 9.50E+05 | 2.70E+05 | 0.65 |

Notes: Min: minimum value; Mean: mean value (arithmetic means of physicochemical parameters, geometric means of bacteriologic parameters); Max: maximum value, $n = 13$. Efficiency: % ($BOD_5$, COD, SS); log units (TC, FC, *E. coli*, FS).

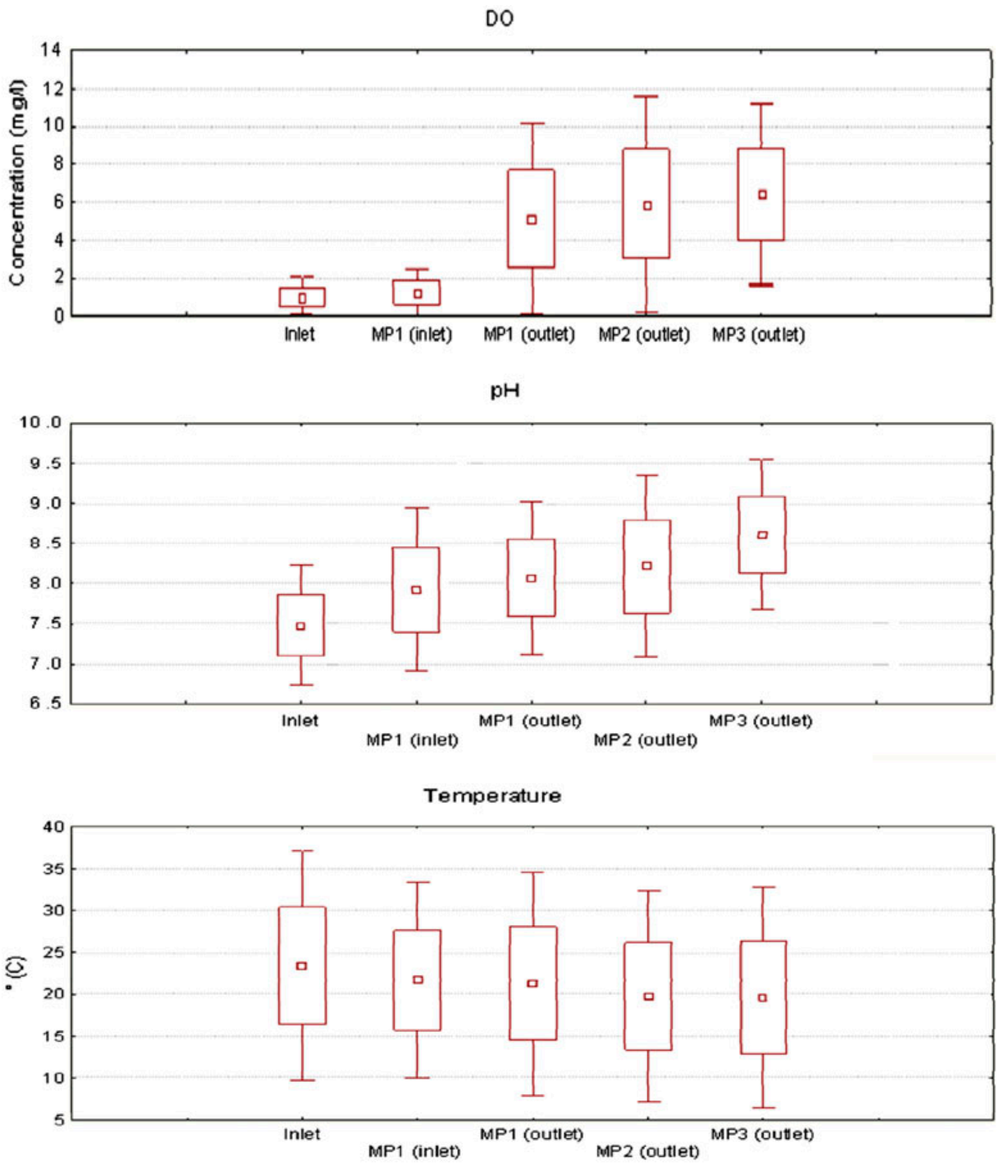


Fig. 2. Box-plot of the DO, pH, and temperature from the routine monitoring.

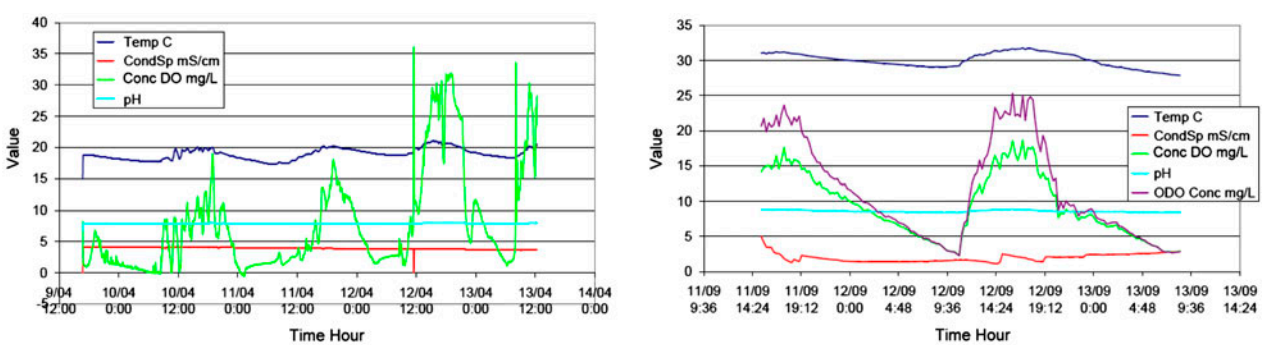


Fig. 3. Diurnal continuous records of temperature, pH, and DO in maturation ponds.

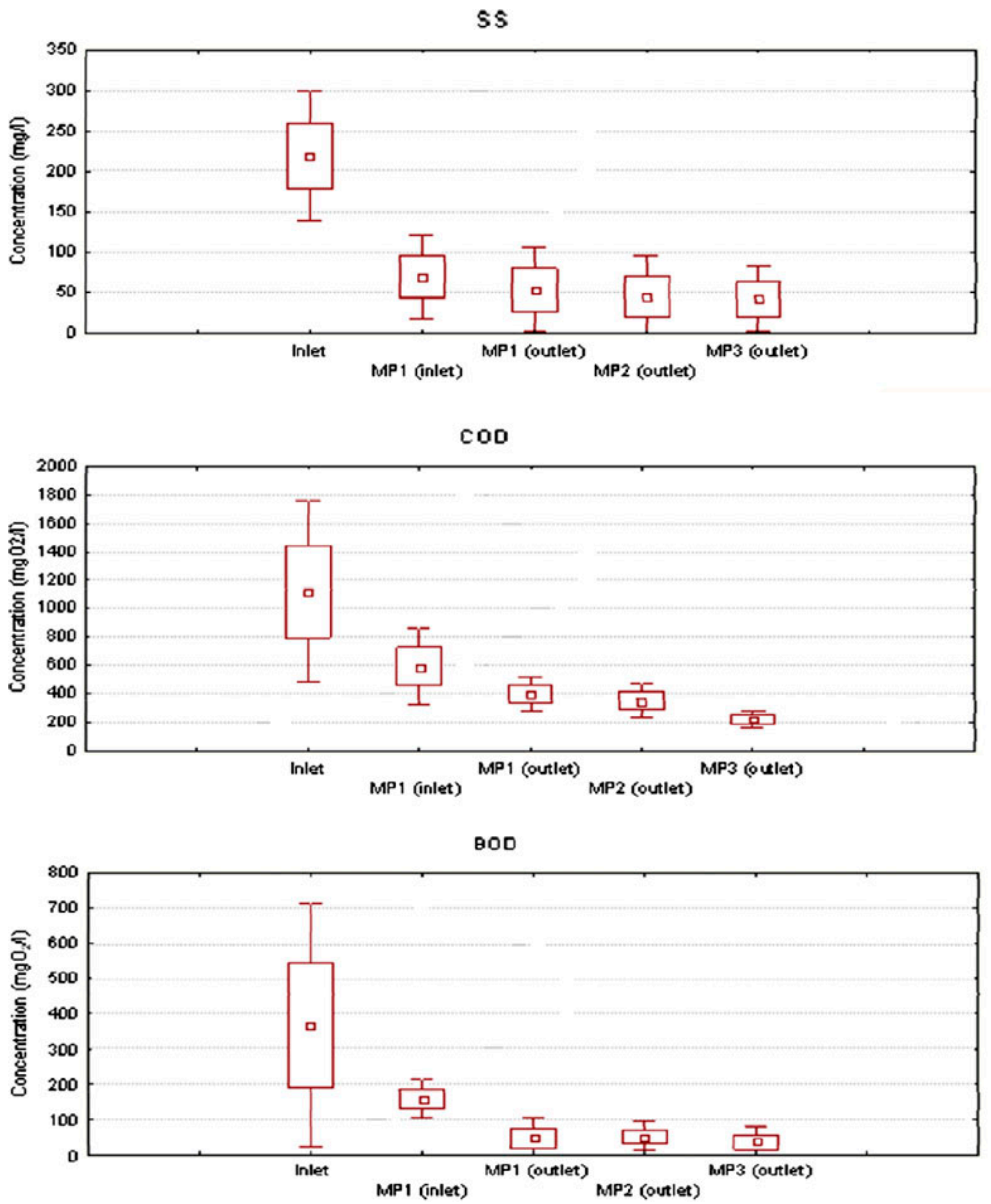


Fig. 4. Box-plot of the concentrations of SS, COD, and BOD from the routine monitoring.

The BOD, COD, and SS concentrations in the maturation ponds in series did not undergo major changes. The SS concentration in the maturation ponds was affected by algal biomass production, which leads to high values of SSs, and consequently, BOD, and COD. Maynard et al. [21] confirmed the following conclusion: the concentration of BOD and SS in the final effluent increases if there are large algal blooms. Mara et al. [22] while working on a tertiary lagoon confirmed the increase of the BOD concentration from 50 to 90%. This increase could reach higher values, up to 160–240% according to Mayo and Noike [23]. The BOD removal was primarily due to the oxidation of organic matter by the heterotrophic bacteria. The oxygen produced by algae during photosynthesis supplies the most important part of the needs of these bacteria, the remainder comes from mass transfer from the atmosphere.

### 3.3. Phytoplankton and zooplankton

Figs. 5 and 6 summarize the composition of phytoplankton and zooplankton in the maturation ponds, respectively. Four phytoplankton classes were

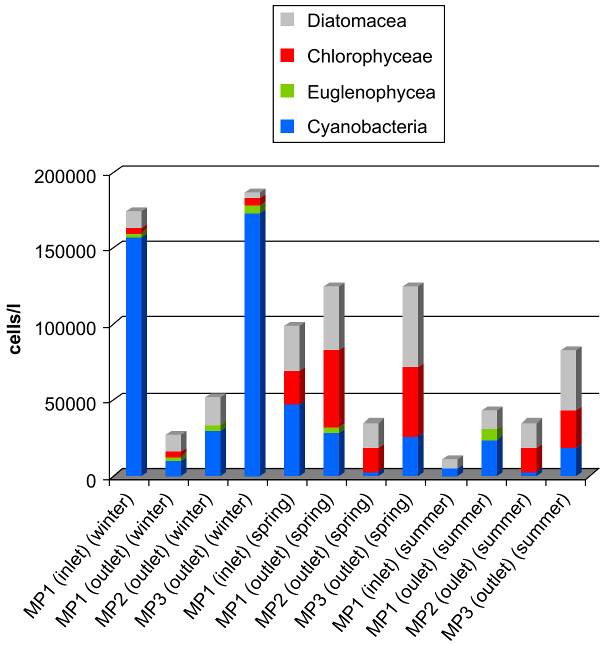


Fig. 5. Composition of the phytoplankton in the maturation ponds.

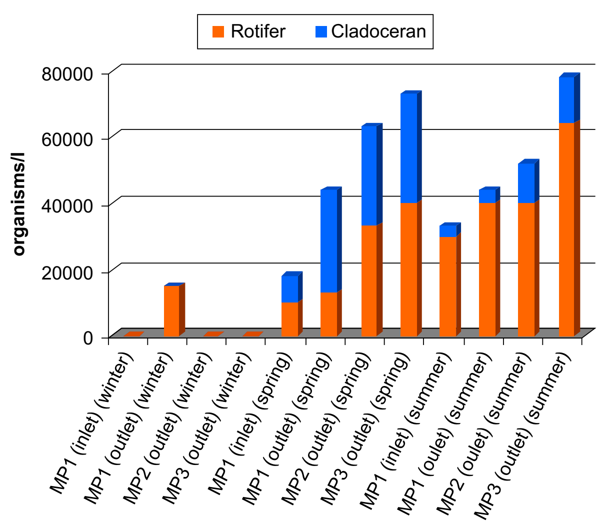


Fig. 6. Composition of the zooplankton in the maturation ponds.

recorded during the intensive monitoring period from winter to summer 2008 (Cyanobacteria, Chlorophyceae, Euglenophyceae, and Diatoms). Two different zooplankton species were recorded during the same period. The zooplankton community structure of the maturation ponds was generally dominated by rotifers and Cladocerans.

The seasonal qualitative monitoring of phytoplankton showed that Cyanobacteria represent an annual average of 24–40% of the algal population, the Chlorophyceae were the second most abundant zooplancton group, representing14–28%. Diatoms and Euglenophyceae represent 6–11% and 1–2%, respectively [24]. The algae population composition was dependent on the seasons; Cyanobacteria (*Oscillatoria prolifica*) predominate in winter and high densities of Cyanobacteria were observed in the MP3. In spring and summer, the Chlorophyceae (*Chlamydomonas* sp.) dominates in the MP2 and MP3. Athayde Júnior et al. [25] related that *Chlamydomonas* was the most pollution tolerant in WWSP. Despite the abundance of phytoplankton species during summer, it remains lower than during the winter season. This could be explained by the grazing of algae by zooplankton. Indeed, an increase of the phytoplankton biomass observed in winter is related to the decrease of the organic and mineral load and the absence of zooplankton phytophagous (*Moinidae* and *Rotifer*) [26]. This explains the high concentration of SS in water during winter. The development of Rotifers (*Brachionus calyciflorus*) and Cladoceran (*Moinidae*) cause the reduction of the algae concentrations, which contribute to cleaning the water of ponds. The presence of a monospecific Cladocerans stand type Monidae proves a very advanced state of water dystrophy in different ponds. Indeed, Moinidae Cladocerans are best suited to high organic loads [24]. This is consistent with the high values of SS and BOD measured at the outlet of the maturation ponds.

Improving abiotic conditions in spring (rise in temperature, photoperiod, and light intensity) and the presence of nutrients in summer promote more algal diversity and density (*Cyanobacteria(Oscillatoria*), chlorophyceae (*Chlamydomonas*.sp.), Euglenophyceae (*phacus*) and Diatoms (*Cyclotella*). Our findings are consistent with those of Craggs and Park [27]. They also found a seasonal variation of biomass algae/bacteria. Furtado et al. [28] assign the abundance of Cyanobacteria to environmental conditions such as high level of nutrients (nitrogen and phosphorus), alkaline conditions of the medium, and high hydraulic retention time. Pastich et al. [29] and Park et al. [15] conclude that the highest densities of total phytoplancton coincide with higher temperatures. They showed that after a high algal biomass growth, the shading phenomenon begins because of the increased particulate matter resulting from the algae.

However, this algal development is offset by the exuberant development of rotifer and Moinidae, which contribute to the clarification of waters by algae grazing. The highest algal production recorded in winter is associated with a low zooplankton biomass. The dominant species are Cyanobacteria and Euglenophyceae. The abundance of phytoplankton species during summer can also be explained by the presence of ammonium at high pH. Oudra [30] showed that in maturation pond, SS removal may be due to the hydrolyzation of organic matter by certain micro-organisms. Kawai [31] confirmed that zooplankton biomass is an effective biological filter in removing SSs, BOD, and bacterial load.

### 3.4. Removal of Bacteria (*E. coli* and streptococci)

The removal of *E. coli* and streptococci in maturation ponds is presented in Fig. 7. Most of the works on bacterial removal assumed that temperature was the key factor controlling the removal mechanism. However, the recent works on bacterial removal in the ponds have considered that the mechanism is much more complex. It involves the interaction between the physical, chemical, and biological parameters, although temperature remains an important factor [14,16,32].

During winter, the treatment efficiency does not exceed 1.5 log units for *E. coli* and fecal streptococci. The purification yields obtained are most important during the summer season (from May until September). The treatment efficiency during this period exceeds 2 log units. The total treatment efficiency of the WWTP (including maturation ponds) exceeds 3 log units. This period was also characterized by a high concentration of DO (10–12.5 mg/l) and high pH (8.63–9.62). The same results are presented by [33]. This reduction is mainly due to solar energy [34] and sunlight duration. During summer with high temperatures and a lot of algal activity, the pH of the water increased in the ponds; Mezrioui et al. [35] have found that the population of *E. coli* decrease rapidly. Curtis et al. [32] discovered that the damage caused by the sunlight on the cytoplasmic membranes of the bacteria leaves these organisms more sensitive to other factors and particularly to the pH.

Maïga et al. [20] found high efficiency of *E. coli* removal when pH exceeds 8.5. These results are also confirmed by Davies-Colley et al. [14]. In this situation, high pH increases the production of toxic forms of oxygen which may damage the cell membrane and cause death. As was reported by Madigan et al. [36], most bacteria of intestinal origin cannot tolerate pH higher than 9, and saturated oxygen levels. Curtis et al. [32], Trousselier et al. [37], and Pant and Mittal [38] observed that the decay of pathogenic bacteria which occurs in maturation ponds is mainly due to a combination of factors such as sunlight, high pH, and high concentration of DO, coinciding with algae photosynthesis activity. Bolton et al. [5] has established that *E. coli* removal from WWSP is due to a combination of sunlight acting alone and in combination with

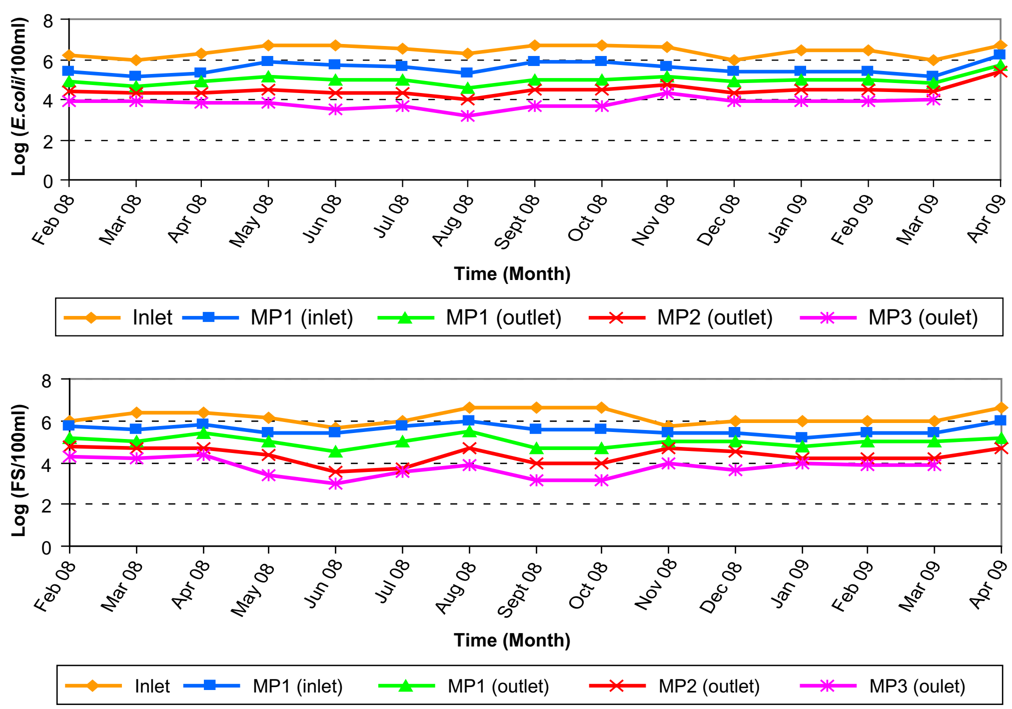


Fig. 7. Evolution of *E. coli* and fecal streptococci in maturation ponds.

photosensitisers, DO, high pH, predation, and settling associated with particulate matter. The amount of produced reactive oxygen species depends on the DO concentration, the concentration and composition of photosensitisers in the wastewater, as well as the incoming solar radiation [14].

The temperature of water is affected by sunlight and it influences the algal growth, as well as other factors such as pH and DO. These parameters have a bactericidal action in wastewater [23,32].

## 4. Conclusion

This work shows the efficiency of the maturation ponds to improve the quality of treated water from existing activated sludge treatment plants.

Maturation ponds are not usually designed for the removal of BOD, since they are polishing lagoons, and are therefore primarily for pathogen and nutrient removal. Treated wastewater reaching the tertiary treatment stage should normally be at, or below, the discharge level.

The phytoplankton in a maturation pond treating domestic wastewater was dominated by the Cyanobacteria. As a result of seasonal environmental changes, the floristic composition in the pond has also changed.

Regarding the influence of operating conditions on the decay of *E. coli* and streptococci in the ponds, a predominance of high pH, DO, and temperature was observed. The hourly variation of pH, temperature, and DO appear to follow the pattern of the diurnal cyclic nature of sunlight intensity.

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