Reuse of reclaimed wastewater for golf course irrigation in Tunisia

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Abstract In Tunisia, golf courses are irrigated with secondary treated effluent stored in landscape impoundments. The impact of the conveyance and storage steps on the physical-chemical and biological quality of irrigation water was evaluated on three golf courses over two years. It was found that the water quality varies all along the water route, from the wastewater treatment plant up to the irrigation site: nutrient and bacteria contents decreased along the route in the three cases. This variation depends on the wastewater quality, the length of the pipes conveying water, the number of regulation reservoirs and ponds, the water residence time in pipes, reservoirs and ponds, and the operation of the ponds. The bacteriological quality of irrigation water deteriorates during the irrigation period in the three golf courses as the ponds are operated as continuous flow reactors. The results obtained in this study indicate the inability of golf water supplies, as currently managed, to properly sanitize reclaimed wastewater and meet target quality criteria recommended by WHO (1989) for water intended for recreational use. For a safe reuse of reclaimed wastewater for golf course irrigation, changes in the design and operation of the ponds should be planned or additional treatment steps provided.

Keywords Algae; bacteria; golf course irrigation; nutrients; wastewater reuse; wastewater storage

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Introduction

Quality of reclaimed wastewater used to irrigate recreational areas with free access to the public is generally submitted to high quality requirements. In the world, several golf courses are irrigated with reclaimed wastewater such as in France (Anonymous, 1991), in South Africa (Jagals and Lues, 1996), in Spain (Mujeriego and Sala, 1991), and in the United States (USGA, 1994). Reclaimed wastewater is either tertiary treated in the treatment plant, or in the golf course. Precautions of use are also generally observed such as night irrigation, use of low range sprinklers, green belts around the course, and signs indicating the water type.

In Tunisia, reuse of reclaimed wastewater for recreational purposes and more particularly for golf course irrigation is an important component of the development of tourism. The eight existing Tunisian golf courses are thus irrigated with reclaimed wastewater (RWW). Precautions of use such as night irrigation with low range sprinklers are applied; however, there are still no standards specific to this type of reuse. Secondary treated wastewater, conveyed and stored in ponds on the golf course during different detention periods depending on the operational regime, is used for irrigation. In order to evaluate the performances of the systems and the quality of the irrigation water, a study was undertaken on three golf courses and over two years from May 1997 to May 1999. The main objectives of this study were (i) to investigate the impact of the operation of the water supply system on the physical-chemical and biological quality of the water during the conveyance and storage steps, and (ii) to evaluate the quality of the irrigation water used on the golf courses and its spatio-temporal variability, in order to recommend ways of improving the golf courses systems as to meet the water quality requirements.

Materials and methods

Carthage, Yasmine, and Kantaoui golf courses

The three studied golf courses are : Carthage in La Soukra, Yasmine in Hammamet, and Kantaoui in Sousse (Table 1). Wastewater, secondary treated in activated sludge plants, is transported in pressurized pipes, and stored in ponds in series, located in the golf courses, before use for irrigation. Yasmine golf course is irrigated with reclaimed wastewater blended with groundwater when the salinity of RWW is too high. Ponds have, for aesthetical reasons, special configurations and geometries and are generally 1 to 5 m deep. Kantaoui golf course has two different distribution systems, a first one (Kantaoui 1) including three ponds (3.1, 2.9, 3.4 m deep), and a more recent one (Kantaoui 2) with a larger pond (5 m deep). Golf courses are irrigated with low range sprinklers according to night programmes. In summer, ponds are filled up in the morning after night irrigation.

The three golf courses are located in semi-arid areas with mild and rainy winters, and hot and dry summers. Average maximum temperatures (33°C) and evaporation (7.3 mm/d) are recorded in July and August, whereas rainfall occurs mainly from September to March. Average annual precipitations in La Soukra, Hammamet, and Sousse are respectively 470, 448, and 388 mm.

Sampling strategy

Different sampling strategies were set-up in order to evaluate the physical-chemical and biological quality of water and its space-time variability. In the case of the Carthage golf course, a more intensive survey was carried out in order to provide more insights into the distribution and storage phases.

Monitoring of the water quality along the water route.

- A monthly monitoring of the water quality all along the water route, i.e. the treatment plant, the main, the ponds, the tank from which water is pumped into the irrigation network and the sprinklers (5 to 8 sampling points from the inlet of the wastewater treatment plant up to the sprinkler) was carried out for the three golf courses during one year and a half, from May 1997 to May 1999.
- Inflows and outflows of the storage ponds were monthly sampled on the different sites. In the case of the Carthage golf course, the two ponds were also daily sampled during summer 1997 while during winter 1997/1998 and spring 1998, samples were taken once to twice a week. Phyto- and zooplankton analyses were carried out every week from

Table 1 Characteristics of the water supply systems

System step		Golf course		
		Carthage	Yasmine	Kantaoui 1 and 2
Wastewater Treatment Plant	Name	Cherguia	SE_1	Sousse Nord
	Process		Activated sludge	
		Average-load	Low-load	Low-load
Supply System	Regulation reservoirs	2	–	–
	Capacity	5,800 and 3,800 m^3	–	–
	Main pipe length	6,800 m	3,700 m	1,900 and 3,600 m
	Main volume	> 2,000 m^3	260 m^3	240 and 323 m^3
Storage Ponds	Number of ponds	2	2	3 + 1
	Maximum depth	5 (B1) and 1.45 m (B2)	1.9 and 2.9 m	3.1, 2.9, 3.4 and 5 m
	Pond capacity	6,000 + 7,000 m^3	18,000 + 35,000 m^3	49,875 + 24,000 m^3
	Total pond capacity	13,000 m^3	53,000 m^3	73,875 m^3
Irrigation site	Irrigated area	18 ha	40 ha	90 + 20 ha
	Number of holes	18	27	36
	Irrigation system		Low range sprinklers	

February to April 1998, i.e., 10 samples per pond, at the first pond outlet (B1), and in the middle of the second one (B2), 20 cm from the surface.

- Irrigation water samples (replicated 2 to 5 times) were monthly taken from May 1997 to May 1999 at the three golf courses (Carthage, Yasmine, and Kantaoui) except in October and November. Final effluent for irrigation was, depending on the irrigation schedule, sampled at the outflow of the last pond, in the tank of the irrigation pumping station or from the sprinklers. Sixty-seven, 50, 35, and 34 samples were respectively taken in total from Carthage, Yasmine and Kantaoui 1 and 2 golf courses.

Analyses. The following analyses were carried out in the laboratory on grab samples:

- Physical-chemical analyses: pH, electrical conductivity (E.C. at 25°C), suspended solids (SS), chemical oxygen demand (COD), Kjeldahl nitrogen (NK), ammonia (NH_4), phosphate ions (PO_4), potassium (K), according to French standards for water analysis (AFNOR, 1979). Dissolved oxygen (DO) was measured with a WTW oxymeter.
- Biological analyses: total (TC) and faecal (FC) coliforms, *Escherichia coli* (EC), faecal streptococci (SF) using the "Most Probable Number" method (AFNOR, 1979); helminth eggs counts using the WHO (1989) recommended technique, carried out on 5 litre samples; phyto- and zooplankton, by means of the Uttermohl method (1958) on 1 litre samples.

Results and discussion

Hydraulic operation and water residence time in the supply systems

The operation of supply systems is controlled by the irrigation needs. Water detention times in the mains and regulation reservoirs are long in winter and short in summer. The average residence time in the main of Carthage golf course, evaluated from the operating time of the pumps over the period 1995–1997, varied from 2 weeks in winter up to 2 days at the peak of the irrigation period (Figure 1). Water detention time in Yasmine and Kantaoui's mains was only several hours, due to main volumes ten times less and larger water demand.

In the same way, based on the monitoring of the water consumption of Carthage and Yasmine golf courses, it was found that the residence time of water in the ponds was highly variable, according to climatic conditions. It was long in winter and short in summer. Theoretical residence time in the ponds (calculated as the maximum capacity of the ponds divided by the ponds' outflow) varied on average from 7 to more than 30 days and could

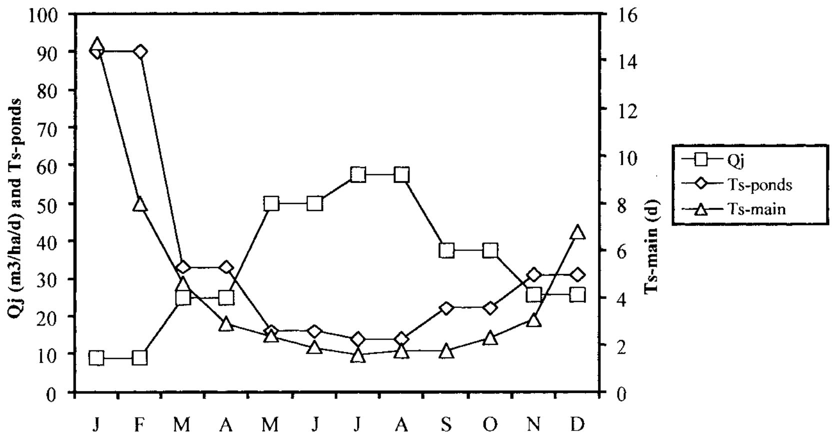

Figure 1 Average detention time in the mains (Ts-distribution) (1995–1997 data), and the ponds (Ts-ponds), and average water consumption (Qj) (1993–1997 data) for Carthage golf course.

reach several weeks. Ponds were intermittently fed in winter, with long residence times, and almost continuously in summer; the number of feeding sequences increasing with the start of irrigation in spring. The maximum daily flow during the summer was 950 m^3 for Carthage golf course, 1,500 m^3 for Yasmine, and respectively 3,700 and 1,000 m^3 for Kantaoui 1 and 2. This flow could be equal to zero during the winter season. The daily consumption varied along the year between 7 and 67 m^3/ha/d; the annual average water consumption for the period 1993–1999 being around 12,000 m^3 per hectare, and ranging between 10,000 and 16,000 m^3 per hectare.

Impact of mains and ponds on the water quality

Physical-chemical parameters along the water routes. All along the three systems, i.e. from the inlet of the wastewater treatment plant up to the sprinklers, pH as well as DO tended to increase. Minor variations of the E.C. were recorded whereas SS decreased along the route. Increases in upper layers of the ponds (up to 100 mg/L) were due to algal development. Nk decreased also all along the supply systems (Figure 2) from 16.7, 33.7, and 72 mg N/L respectively in Cherguia, SE1, and Sousse Nord secondary effluent, up to 14.6, 19.1, 51.4, and 38.9 mg N/L respectively in Carthage, Yasmine, Kantaoui 1 and 2 pond effluents. NH_4 followed the same trend as Nk whereas NO_3 fluctuated and NO_2 increased. PO_4 decreased also all along the systems. K was almost not affected and was around 42, 26 and 38 mg/L respectively along the Carthage, Yasmine and Kantaoui systems. Nk removals were recorded in the mains (up to 50% in the Yasmine's main), and varied between 20 and 40% in Carthage and Kantaoui golf ponds. Within the storage ponds, nutrients were eliminated through biological and physical-chemical processes. These processes varied with the climatic and operational conditions and led to the following changes in the ponds.

Physical-chemical quality of golf course ponds. The quality of the water stored during different detention times evolved during the year. Similar changes were recorded on the three sites. Salinity decreased in the ponds in autumn and winter because of rain and increased in spring and summer, because of evaporation. Evolutions of pH, nutrients and suspended solids were correlated. pH increased during the storage period, i.e. from December to May with the development of the photosynthetic activity and decreased from August to January. Phyto- and zooplankton development transformed nutrients into organic matter and this resulted in an increase of the SS content. The SS content of ponds was highly variable (from 5 to 100 mg/L) with quick changes. The SS content was generally lower than 30 mg/L. It

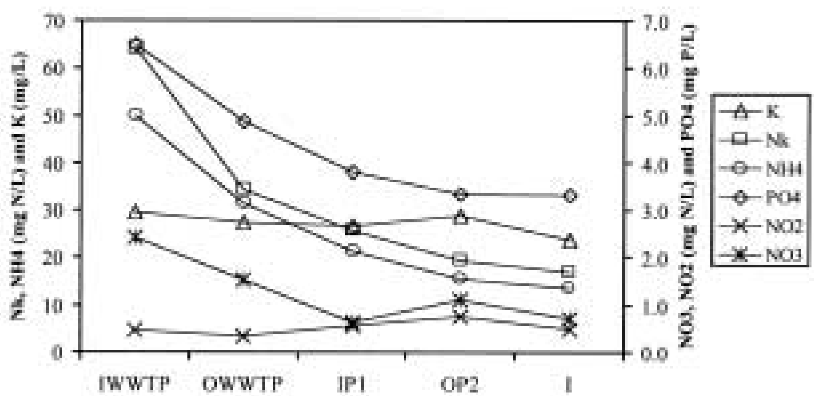

Figure 2 N, P, and K contents along the Yasmine water supply system (IWWTP: inlet WWTP; OWWTP: outlet WWTP; IP1: inlet first pond; OP2: outlet last pond; I: irrigation)

generally increased at the beginning of the storage period and decreased or remained unchanged during winter. The nutrient content decreased during storage (up to less than 5 mg/L of NH_4-N and PO_4-P in Carthage ponds) but was submitted to large variations depending on the golf operation. It was shown that the water quality of the golf course ponds was directly dependent on the flow rate and the quality of inlet effluents, new effluent applications leading to important increases in the N contents of the ponds outflow (Bahri *et al*., 2000).

Phyto- and zooplankton were analyzed in Carthage golf course ponds from February to April 1998 and four indicators (T°C, pH, dissolved oxygen (DO), and chlorophyll a) were used to characterize their development. Phyto- and zooplankton developed successively during the season in the first pond (B1). In the second one (B2), the plankton development seemed stabilized but the zooplankton density was lower and more regular compared to B1. pH, DO, and Chl a had similar patterns in the two ponds. Peak values corresponded to the sunniest periods of the season. pH (ranging between 7.3 and 8.4) and DO (varying from less than 2 to nearly 8 mg O_2/L) values were lower in B1 compared to B2 (pH varying from 7.7 to 9.7 and DO from 6 to more than 14 mg O_2/L). This may be explained by a more intense respiration in B1 due to the bacteria concentration and zooplankton density. The specific diversity of phytoplankton decreased between the end of winter and spring with the increase of the nutrient content. Monospecific phytoplankton blooms, specific to each pond were observed at the beginning of March. Phacus (Euglena) settled in the second pond, involving a change of the water color (turning to green) and an increase in the Chl a content (from some µg/l at the beginning of March to more than 300 µg/L at the end of April). Thus, similar phytoplankton densities in the two ponds can lead to different biovolumes (the Phacus cells' size is larger than that of Ankistrodesmus ones), expressed, in particular, by the Chl a content (which did not exceed 20 µg/L in B1). The specific conditions and characteristics of each pond (depth) determined the represented species.

Bacteriological parameters along the water routes. The bacteriological quality of RWW improved all along the water route, i.e. from the inlet of the wastewater treatment plant up to the sprinklers (Figure 3). The same trend was observed for all the monitored parameters (TC, FC, EC, and FS).

The three WWTPs had FC removals varying between 1.6 and 2 log units Between the outlet of the WWTP and the inlet of the first pond, average FC removals of 1.5 to 2.8 log units were recorded whereas they were ranging from 0.4 to 1.3 log unit between the inlet of the first pond and outlet of the last pond of the golf courses, the three ponds in series of Kantaoui 1 having the highest removal efficiency (Table 2). Analyses carried out on reclaimed wastewater, after 14 days residence time in the main (4 km long, 600 mm diam.) linking the two regulation reservoirs supplying the Carthage golf course, showed TC and FC removal of 1 to 2 log units. However, average values of pond removal were rather low especially during summer, despite high solar radiation and algal development. These poor bacteria removals were due to frequent fresh secondary effluent supplies, shorter residence times in the ponds, and sludge accumulation, such as in the case of Yasmine ponds.

Mains (anaerobic conditions) had then higher removal efficiencies compared to the golf course ponds (aerobic conditions). Residence time of the water in the mains and in the ponds led to average FC removals equal to 2.8 log units respectively for Carthage, Yasmine, and Kantaoui 1, and 3.2 log units for Kantaoui 2. Differences noticed between Kantaoui 1 and 2 illustrate the mains efficiency in the case of Kantaoui 2 and the ponds efficiency in the case of Kantaoui 1. A larger variability of the bacteriological water quality was also noticed at the pond and irrigation steps (standard deviation (σ) of the FC count was around 1 log unit) compared to the other steps ($\sigma \approx 0.5$ at the inlet and outlet of the WWTP).

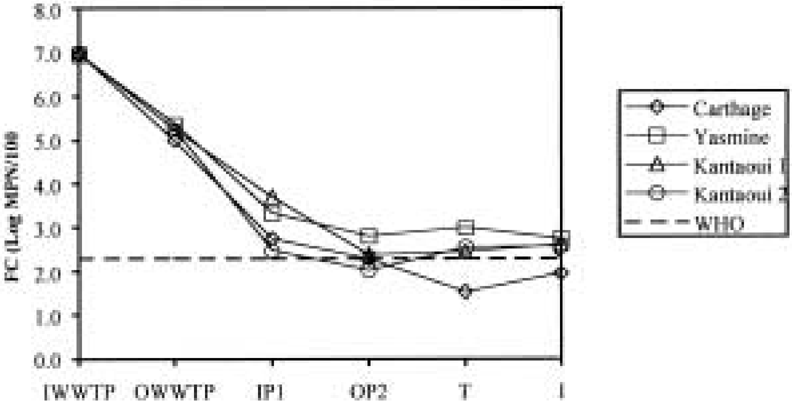

Figure 3 Average FC content along the three water routes (IWWTP: inlet WWTP; OWWTP: outlet WWTP; IP1: inlet first pond; OP2: outlet last pond; T: tank; I: irrigation)

Table 2 Faecal coliform removals along the three water supply systems (log units)

	Carthage	Yasmine	Kantaoui 1	Kantaoui 2
Inlet – outlet WWTP	2.0	1.6	1.8	1.8
Outlet WWTP – Inlet pond 1	2.3	2.2	1.5	2.8
Inlet pond 1 – Outlet last pond	0.5	0.6	1.3	0.4
Total	4.8	4.4	4.6	5.0

This was due to operational and environmental variability factors. However, a more intensive survey carried out on the water quality of Carthage golf ponds showed that higher bacteria removals may be achieved: FC removals around 4 log units were recorded at the end of the winter and of 1 log unit in summer (Bahri *et al.*, 2000). Improvement of the storage step by increasing sunlight exposure with increased residence times could enhance pond disinfection (Davies-Colley *et al.*, 2000). Batch operation is also highly recommended.

Irrigation water quality

Physical-chemical parameters. Monthly values of pH varied between 6.9 and 9.4. They decreased in winter and increased in spring and autumn. A higher average value of the electrical conductivity of irrigation water was recorded on Carthage golf course and a lower one at Kantaoui 1 (Table 3). Important differences were observed from year to year with higher values in 1997–98 compared to 1998–99. The lowest values were observed in autumn and winter. Peak values (up to 9–10 dS/m), which may be due to some seawater intrusion in the system, were observed in summer particularly at the Carthage golf course.

Suspended solids had similar patterns along the year on the three courses with increasing concentrations in spring and summer and decreasing ones in autumn and winter (<10 mg/L). Values exceeding the irrigation Tunisian standards of 30 mg/L (NT 106.03, INNORPI, 1989) were recorded on Yasmine golf course in March and May leading to some clogging of the sprinklers. Nutrient contents (N, P, K) were highly variable from year to year and along the year. Larger N values were recorded at Kantaoui and K ones at Carthage. Nk ranged from 3 to 35 mg N/L at Carthage, 4 to 53 mg N/L at Yasmine, 7 to 88 mg N/L at Kantaoui 1, and 4 to 74 mg N/L at Kantaoui 2. PO_4 varied between 0.6 and 6.9 mg P/L at Carthage, 1.6 and 4.9 mg P/L at Yasmine, 1.2 and 8.8 mg P/L at Kantaoui 1, and 1.1 and 8.0 mg P/L at Kantaoui 2. N supplied by irrigation water fulfilled the grass requirements but the water nutrient content was only taken into account in the fertilization programme of Kantaoui golf course.

Table 3 Average irrigation water quality of the three golf courses

	Carthage			Yasmine			Kantaoui 1			Kantaoui 2		
	Mean	σ	N	Mean	σ	N	Mean	σ	N	Mean	σ	N
pH	8.02	0.55	50	7.78	0.39	46	7.77	0.27	32	7.78	0.30	31
E.C. (dS/m at 25°C)	3.81	1.24	51	3.39	0.48	50	3.24	0.41	35	3.25	0.30	34
SS (mg/L)	16.6	7.9	46	25.2	24.9	50	13.1	6.5	32	14.9	13.2	33
Nk (mg N/L)	11.4	7.9	41	17.0	9.3	50	48.6	21.1	23	32.1	14.4	29
Pt (mg P/L)	5.1	2.7	33	4.8	1.7	29	6.8	2.7	19	5.4	1.8	22
PO_4 (mg P/L)	2.8	1.6	45	3.3	0.9	39	5.4	1.7	28	4.5	1.5	30
K (mg/L)	42.7	9.9	49	23.8	7.6	48	37.0	12.2	32	37.4	13.9	33
TC (Log MPN/100 mL)	2.56	1.04	64	3.44	0.91	49	3.31	0.83	34	3.14	1.01	30
FC (Log MPN/100 mL)	1.96	0.90	65	2.77	1.10	49	2.62	0.95	34	2.59	1.07	28
EC (Log MPN/100 mL)	1.66	0.90	67	2.42	1.13	49	2.16	1.03	33	2.12	1.01	28
FS (Log MPN/100 mL)	2.02	0.68	65	2.54	0.90	49	2.33	0.62	33	2.49	0.85	28
Helminth eggs (/L)	0		67	0		49	0		33	0		31

σ: standard deviation; N: number of samples

Bacteriological parameters. TC, FC, EC, and FS content of irrigation water, monitored during two years, had similar patterns. Water was in compliance with the WHO guidelines for wastewater reuse on recreational areas with free access to the public (1989) (200 FC/100 mL) from October to March for Carthage and Kantaoui courses and from December to March for Yasmine course (Figure 4).

The best quality was recorded for the three courses in January and February, with a FC content around 1 log unit. The water quality deteriorated during the irrigation period, i.e. from April to September: the FC content reached and even exceeded 3.5 log units in the three cases. In the Mas Nou golf course, an increase in the microorganisms content was also recorded in summer in the two storage ponds (Mujeriego and Sala, 1991). The best irrigation water quality was recorded all along the year in the irrigation water of Carthage golf course; additional bacteria removal was observed between the outlet of the last pond and the tank of the irrigation pumping station (Figure 3). Whereas some contamination of the water occurred in the tank of the pumping station at Yasmine and Kantaoui golf courses.

Conclusion

The study conducted on three golf courses irrigated with reclaimed wastewater showed similar results on the three sites.

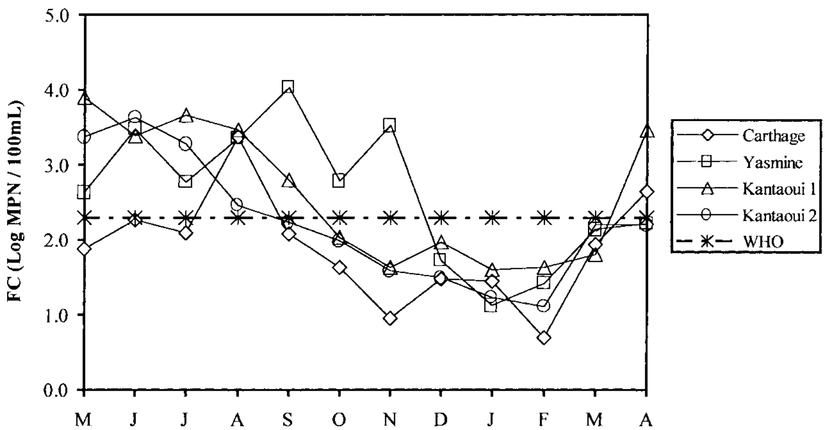

Figure 4 Average FC content of irrigation water of the three golf courses

- The water quality varies all along the water route, from the wastewater treatment plant up to the sprinkler. This variation depends on the wastewater quality, the length of the mains conveying water from the wastewater treatment plant up to the golf course, the number of regulation reservoirs and ponds, the residence time of water in the mains, the reservoirs, and the ponds, and the operation of the ponds as continuous flow or batch-flow reactors.
- The nutrient and bacteria contents decreased all along the three water supply systems. A larger variability of the bacteriological quality of the pond and irrigation water was noticed due to the operational regime.
- The mains had higher bacterial removal efficiencies (FC removal of 1.5–2.8 log. units) compared to the golf course ponds (FC removal of 0.4–1.3 log. units).
- Irrigation water was in compliance with the WHO guidelines for wastewater reuse on recreational areas from October to March. The best water quality was obtained for the three courses in January and February. The bacteriological quality deteriorated during the irrigation period as the ponds were operated as continuous flow reactors, i.e. from April to September.

The results obtained in this study indicate the inability of the water supply systems, as currently managed, to properly sanitize reclaimed wastewater to meet target quality criteria proposed by WHO (1989) for water intended for recreational use. This is largely due to increased hydraulic loads during the irrigation period shortening effective retention time in the ponds. A sequential operation of the ponds, with alternating closing and opening periods, would improve the water quality up to the required standards. For a safe reuse of reclaimed wastewater for golf course irrigation, changes in the design and operational characteristics of the ponds should be planned or additional treatment steps should be provided.

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