Applied Water Science (2020) 10:7
https://doi.org/10.1007/s13201-019-1095-5

ORIGINAL ARTICLE

Irrigation of a golf course with UV-treated wastewater: effects on soil and turfgrass bacteriological quality

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Received: 27 February 2018 / Accepted: 30 October 2019 / Published online: 13 November 2019

Abstract

This research was carried out to assess the impact of treated wastewater irrigation on soil bacteriological and physicochemical properties and turfgrass bacteriological quality. Two golf courses were studied: a golf course A irrigated with freshwater (FW) and a golf course B irrigated with UV-treated wastewater (UV-TW). The physicochemical parameters (electrical conductivity and pH) of the soil were determined. FW, UV-TW, lake-stored water (LSW), turfgrass, and soil were collected, and their bacteriological parameters were determined. These parameters include: *Escherichia coli*, faecal enterococci, and faecal coliform. The results showed that the soil irrigated with treated wastewater (S-TW) showed a significant increase in the pH when compared with the soil irrigated with freshwater (S-FW). However, no significant difference was recorded in soil electrical conductivity. Faecal indicators concentration of the irrigation water samples varied considerably, and the concentrations in LSW frequently exceed those of the water at the output of the treatment plant (UV-TW). The comparison of the faecal contamination between the two golf courses indicates no significant difference in *E. coli* and faecal coliform concentrations. However, a significant difference was detected in faecal enterococci contamination. This study confirms that, under appropriate conditions, treated wastewater produced by M'zar wastewater treatment plant can be used as an alternative water resource for golf courses irrigation in Agadir city, Morocco.

Keywords Faecal contamination · Morocco · Irrigation · Physicochemical parameters · Treated wastewater

Introduction

The water resources constitute a social and economic problem in many countries of the Middle Eastern and North African (MENA). This situation refers to climatic conditions and increasing population growth. Morocco is located in these regions characterized by scarcity of conventional water. The estimated volume of wastewater generated in Morocco is 640 million (m^3) in 2010. The volume will increase to 870 million (m^3) in 2020 and to 1039 million (m^3) in 2030. The direct use of treated wastewater concerns, currently, the agricultural sector, watering golf courses, and green areas. Only 10% of wastewater was recycled in 2008, and the estimated volume will increase to 170 million (m^3) and 325 million (m^3) in 2020 and 2030, respectively (FAO 2016).

Treated wastewater reuse for irrigation is largely applied to agriculture, but we have a large variety of other applications: industrial uses, urban and recreational uses, aquaculture, and groundwater recharge. Many studies have confirmed the benefits of the irrigation with treated wastewater; one of these economic benefits is reducing fertilizer demand (Paranychianakis et al. 2006). The total nitrogen (N) contents, typically, in secondary effluents ranged between 10 and 20 mg L^{-1} (Akponikpè et al. 2011), and the most fraction of the nitrogen (N) and phosphate (P) found in reclaimed water can be easily used by plants (Duncan et al. 2009). In addition to the two elements N and P, reclaimed water is, also, a source of organic matter (Gagliardi and Karns 2002b), calcium, potassium, and magnesium (Gatta et al. 2015) and a variety of micronutrients, such as zinc, manganese, iron, molybdenum, nickel, cobalt, and boron (Qian and Mecham 2005).

Despite the socioeconomic benefits of wastewater reuse in irrigation, this practice poses a number of health and environmental risks. Many studies have shown that microbial

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contamination represents a real risk. A large variety of microorganisms has been isolated from wastewater (Vaz-Moreira et al. 2014). Chemical pollutants pose serious risks to health and the environment; effluents may contain pesticides (Köck-Schulmeyer et al. 2013), heavy metal (Ouali et al. 2008), and substances pharmaceuticals (Gibson et al. 2010).

The golf courses are most often located adjacent to urban areas, and the occasional direct or indirect human contact with water irrigation is likely. In such cases, the guidelines for irrigation of golf courses with treated wastewater are typically more stringent. In many Mediterranean countries, treated wastewater is used in the irrigation of golf courses, and this practice was a subject of previous research (Bahri et al. 2001; Beltrao et al. 2003; Alonso et al. 2006; Candela et al. 2007). Starting in August 2010, treated wastewater of M'zar plant of Greater Agadir (Morocco) origin has been used for irrigation of a golf course (Ocean Golf) located in Agadir city. However, the impact of irrigation with treated wastewater, of 7 years of application, remains a subject not addressed. In this context, our study is the first to evaluate the faecal contamination of soil and turfgrass and the physicochemical parameters of soil. In order to better analyse the cumulative impact of wastewater application, we compared two golf courses irrigated with two types of water. The Ocean Golf Course (golf course B) is irrigated with tertiary treated wastewater, and the Royal Golf (golf course A) which served as the control is irrigated with a FW source from the groundwater local. The bacteriological quality of the FW and tertiary treated wastewater were also evaluated. Faecal enterococci, faecal coliform, and *E. coli* were selected as indicators of faecal contamination. The soil properties including soil electrical conductivity (EC) and pH were also determined.

Materials and methods

Study site

The study area is located in city of Agadir (south of Morocco: altitudes between 30 and 31°N) (Fig. 1). Agadir is an agricultural region, with an arid climate. The M'zar treatment plant was built in 2002; it is the largest treatment plant in the region of Agadir (approximately 8.5 km south of Agadir city), and it is located on the coastal dunes of M'zar within the Souss-Massa National Park. The wastewater treatment is based on an infiltration-percolation process with UV disinfection, and the treatment mode includes three successive stages (Fig. 2): a first stage, in which the wastewater undergoes a primary treatment (treatment capacity: 75,000 m^3/day) for 3 days in 13 settling pond; a second stage, in which decanted water percolates in 24 sand basins (secondary treatment) with a treatment capacity of 10,000 m^3/day; the third stage of treatment system (tertiary treatment with a treatment capacity of 30,000 m^3/day) being disinfection using ultraviolet (UV) light (RAMSA 2002). Bacteriological and physicochemical quality of untreated/treated wastewater is presented in Table 1.

Tertiary treated wastewater (UV-TW) is pumped and stored (LSW) before use in a large lake located on the golf course B (Fig. 2). The golf course B is situated 3 km from the city centre, close to the Bensergao Forest; it was built in 2009 and irrigated since 2010 with UV-TW; the irrigation water source used was a tertiary treated wastewater originated from the M'zar plant. The golf course A was built in 1955; it is chosen as a reference in this study because it is irrigated with freshwater (FW); it is situated around 12 km on the south-east from the centre Agadir, on the north bank of the River Souss.

Fig. 1 Map of the M'zar wastewater treatment plant, golf course B and golf course A located in Agadir city, Morocco

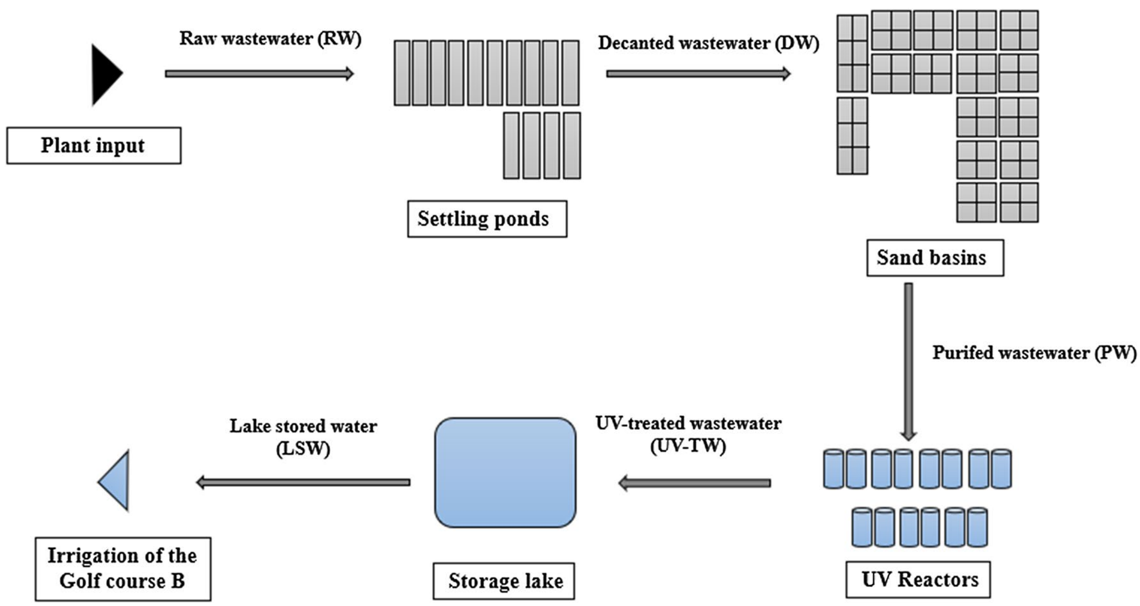

Fig. 2 Schema of M'zar wastewater treatment plant process

Table 1 Bacteriological and physicochemical quality of treated wastewater of the M'zar treatment plant (mean values). *Source*: Bourouache et al. (2019)

	Raw water	Decanted water	Purified water	Purified water treated by UV
pH	7.54	7.37	7.92	7.95
Temperature (°C)	20.15	19.75	19.23	19.53
Electrical conductivity (µS cm^{-1})	2520.00	3002.50	3302.50	3261.50
COD (mgO_2 l^{-1})	1821.50	716.75	44.50	43.00
BOD_5 (mgO_2 l^{-1})	1389.44	385.16	11.52	11.34
TSS (mg l^{-1})	697.81	321.98	6.84	6.50
Faecal coliform (CFU/100 ml)	4.71×10^6	–	–	1.45×10^3
Faecal enterococcus (CFU/100 ml)	2.62×10^5	–	–	7.92

Sampling strategy

Water irrigation (FW, UV-TW, and LSW), turfgrass, and soil samples were collected from February to August 2016. Faecal enterococci, faecal coliform, and *E. coli* were selected as indicators of faecal contamination. Each golf course was divided into three blocks, and a composite of turfgrass and soil samples was taken from each block. Soil samples were taken at depths of 10 cm, because the hygienic characteristics of the soil are slightly affected particularly, in the first 10 cm (Palese et al. 2009). Soil and turfgrass samples were collected in sterile plastic bags, while water samples in sterile glass bottles, and then all samples were stored at + 4 °C. The bacteriological analysis was done within 24 h from samples collection.

Physicochemical parameters

Physicochemical analysis were carried out in triplicate. Soil samples were dried and sieved (< 2 mm) and then were analysed. The pH and the electrical conductivity of soil were determined in distilled water at a soil-to-solution mass ratio of 1:5. The moisture content of the soil was determined by drying 5 g of soil at 105 ± 1 °C for 24 h in a drying oven. The soil temperature was calculated in situ.

Bacteriological analysis

Faecal enterococci, faecal coliform, and *E. coli* were selected as indicators of faecal contamination. For water samples, the membrane filtration method was used to enumerate the indicators of bacteriological contamination. Appropriate volumes of water samples were filtered through 0.45-µm membrane filters (Millipore), with incubation on TTC-Tergitol-Agar for 24 h at 44 °C for faecal coliform (ISO 9308-1), tryptone bile agar with X-glucuronide (TBX agar) for 24 h at 44 °C for *E.coli* (ISO 9308-1), and Slanetz-Bartley agar at 37 °C for 48 h for faecal enterococci (ISO 7899-2).

For soil and turfgrass analysis, ten grams of each sample added to 90 ml of tryptone salt broth was homogenized in a stomacher. Serial dilutions were spread onto plates containing TBX for *E. coli* according to procedure (ISO 16649-2), and BEA agar for faecal enterococci (Pourcher et al. 2007). The same samples were analysed for faecal coliform according to the AFNOR method NF V08-060. All bacteriological analysis were done in triplicate.

Results and discussion

Physicochemical soil characteristics

Table 2 shows the mean values of the physical properties of soil samples. At the time of sampling, mean soil temperature ranged from 15.33 °C to 26.13 °C for S-TW and from 14.80 °C to 27.08 °C for S-FW. The moisture content of the soil varies between 5.97% and 15.5% in S-TW, and 17.4% and 22.33% in S-FW. The texture of the soil in the golf course B was classified as sandy texture compared to soil of the golf course A characterized by a clay texture.

Figures 3 and 4 show the values of pH and electrical conductivity measured in soil, respectively. The average pH of the S-TW was in the range of 8.47 to 9.37. For S-FW, the pH values vary between 8.15 and 9.11. The higher conductivity values were about 803.33 and 679.67 µS/cm for S-TW and S-FW, respectively. The low conductivity measured 324.7 ± 6.3 µS/cm for the S-TW and 474.33 ± 15.53 µS/cm for S-FW. pH was significantly higher (Table 3) in S-TW compared to S-FW. This result is similar to those reported by other authors who observed an increase in the pH value as a result of the treated wastewater irrigation (Adrover et al. 2012; Tarchouna et al. 2010). The increase in soil pH can be attributed to the high content of cations such as sodium ion (Na+), calcium ion (Ca^2+), and magnesium ion (Mg^2+) of treated wastewater (Gelsomino et al. 2006; Tarchouna et al. 2010). No significant difference were found in soil electrical conductivity (Table 3); the same result was found by

Table 2 Main physical soil characteristics (mean values and standard deviation)

Measured parameter	Golf course	February	March	April	May	June	July	August
T (°C)	Golf course B	15.33 ± (2.22)	16.57 ± (1.51)	20.81 ± (0.34)	19.9 ± (0.34)	23.89 ± (0.33)	26.13 ± (0.78)	25.97 ± (0.31)
	Golf course A	14.80 ± (0.46)	20.43 ± (6.07)	22.00 ± (1.07)	22.44 ± (0.5)	24.9 ± (0.85)	27.08 ± (0.14)	26.41 ± (0.27)
Moisture (%)	Golf course B	5.97 ± (1.25)	8.13 ± (0.67)	7.37 ± (0.15)	9.63 ± (2.25)	9.8 ± (1.44)	9.47 ± (0.25)	15.5 ± (0.5)
	Golf course A	22.33 ± (1.53)	17.4 ± (0.53)	17.7 ± (0.33)	17.93 ± (0.58)	20 ± (0.31)	18 ± (0.3)	21.33 ± (0.76)
Texture	Golf course B	Sandy soil						
	Golf course A	Clay soil						

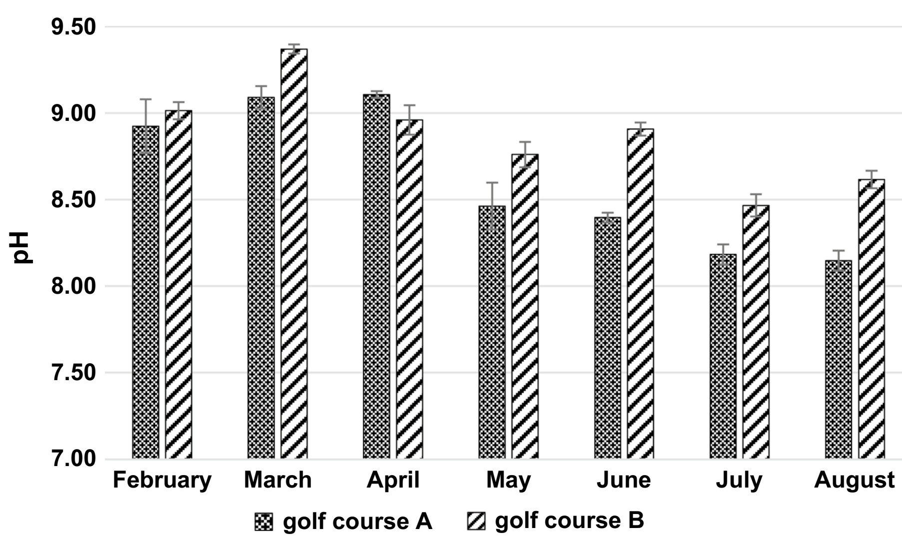

Fig. 3 Monthly variations of pH in soil sampled in golf course A [soil irrigated with freshwater (S-FW)] and golf course B [soil irrigated with treated wastewater (S-TW)] studied from February to August 2016

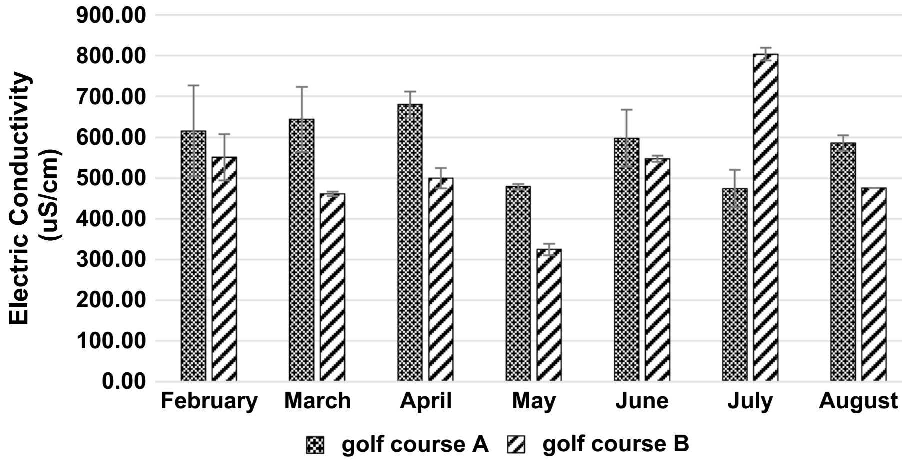

Fig. 4 Monthly variations of electric conductivity in soil sampled in golf course A [soil irrigated with freshwater (S-FW)] and golf course B [soil irrigated with treated wastewater (S-TW)] studied from February to August 2016

Table 3 Descriptive statistics of physicochemical parameters in the soil samples according to the UV-TW and FW irrigation

Physicochemical parameters	Water irrigation used		Significance
	Freshwater	Treated wastewater	
Soil			
Electric conductivity (uS/cm)	582 ± (78)	523 ± (144)	ns
pH	8.62 ± (0.41)	8.87 ± (0.29)	s*

ns not significant, s significant, * $p \leq 0.05$

Chevremont et al. (2013) who studied the impact of watering with UV-LED-treated wastewaters and tap water on soil parameters.

Bacteriological quality of the water irrigation

The bacteriological quality of water irrigation is based on the nature and quantities of contamination indicators it contains. Figures 5, 6, and 7 show, respectively, the concentration of faecal coliform, *E. coli*, and faecal enterococci in water irrigation sampled from February to August 2016. For UV-TW, the highest concentration of faecal coliform (2.7 $\log_{10}$ CFU/100 ml) was detected in February, while in June and August there was a total absence of faecal coliform. For LSW, faecal coliform varied from a minimum of 0.7 $\log_{10}$ CFU/100 ml in August to a maximum of 2.9 $\log_{10}$ CFU/100 ml in June. All FW samples showed no faecal coliform contamination. Faecal coliform levels in UV-TW were always complying with current Moroccan Standards (< 200 CFU/100 ml) with the exception of one sample collected in February (2.7 $\log_{10}$ CFU/100 ml). Variability in the concentration of indicator bacteria is probably due to the

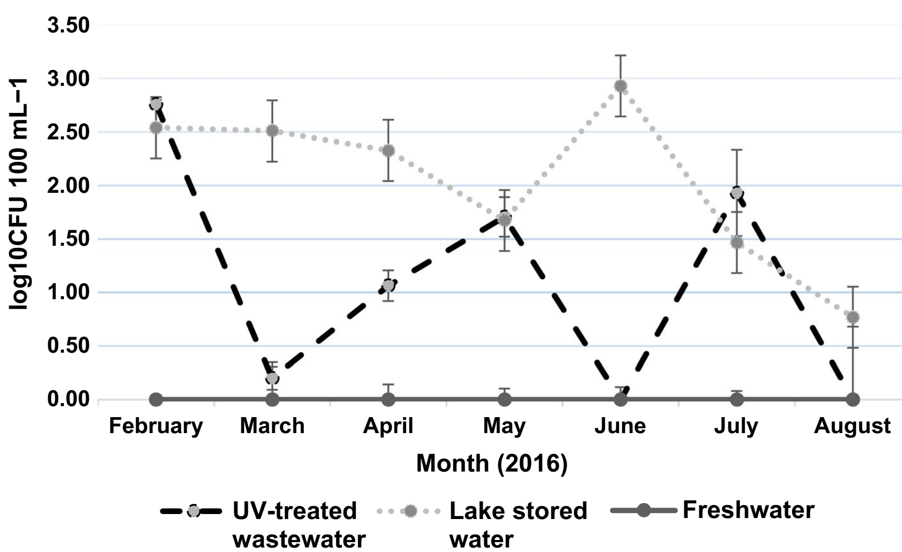

Fig. 5 Monthly variation of Faecal coliform in the irrigation water samples collected from February to August 2016

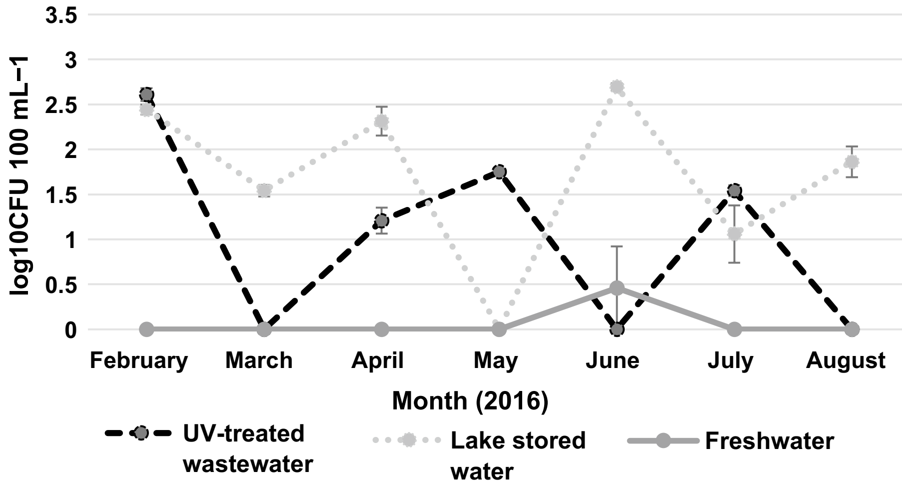

Fig. 6 Monthly variation of *E. coli* in the irrigation water samples collected from February to August 2016

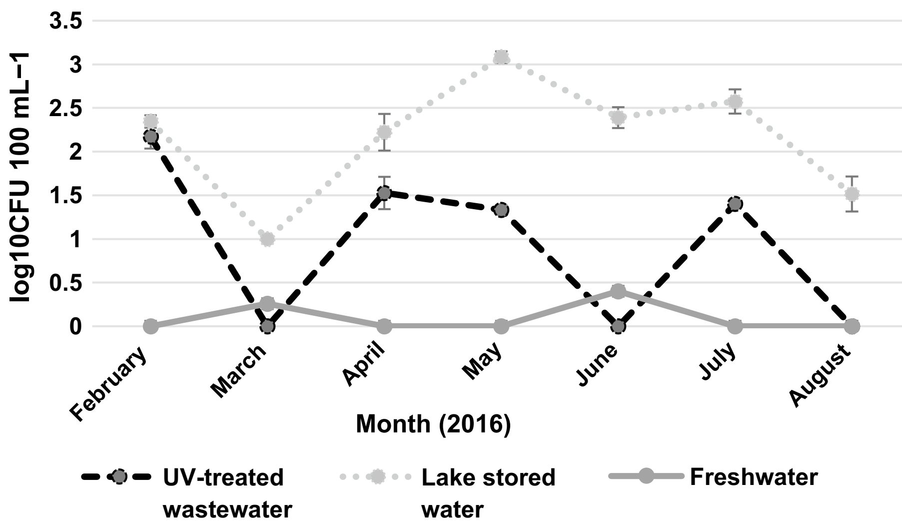

Fig. 7 Monthly variation of faecal enterococci in the irrigation water samples collected from February to August 2016

quality of the effluent entering and to the bad management of the treated wastewater treatment plant (Vivaldi et al. 2013).

E. coli concentration (Fig. 6) varied from 0 (March, June and August) to 2.61 $\log_{10}$ CFU/100 ml (February), from 0 (May) to 2.69 $\log_{10}$ CFU/100 ml (June) for UV-TW, LSW, respectively. For FW, one sample was positive (June).

The concentration of faecal enterococci (Fig. 7) in the water types ranges from 0 (March, June, and August) to 2.17 $\log_{10}$ CFU/100 ml (February), from 1 (March) to 3.08 $\log_{10}$ CFU/100 ml (May), and from 0 to 0.4 $\log_{10}$ CFU/100 ml (June) for UV-TW, LSW, and FW, respectively.

Our results showed a variation with time of the levels of bacteria concentration in treated wastewater. Similar results were found by others authors who studied the effect of wastewater treated use in irrigation (Vivaldi et al. 2013). The levels of faecal coliform, *E. coli*, and faecal enterococci of the irrigation final water (LSW) in golf course B revealed the mean value of 2.03 $\log_{10}$ CFU/100 ml, 1.7 $\log_{10}$ CFU/100 ml, and 2.16 $\log_{10}$ CFU/100 ml, respectively. These values exceed those of the UV-TW at the output of the treatment plant. These high values are probably due to the occasional contamination of the LSW. Many factors have been described as sources of faecal contamination of the environment (Venglovsky et al. 2006; Palese et al. 2009).

Bacteriological quality of the soil and turfgrass

In this study, we assess the effect of irrigation with UV-TW on bacteriological and physicochemical quality of soil and turfgrass bacteriological quality. Faecal coliform concentrations in S-FW and S-TW are shown in Fig. 8. S-FW were contaminated by faecal coliform, with values varying from 3.17 to 5.59 $\log_{10}$ CFU/g. S-TW revealed the presence of faecal coliform in concentrations ranging from 2.97 to 6.61 $\log_{10}$ CFU/g. *E. coli* contamination values of soil can be seen in Fig. 9. The concentrations values varied between

Fig. 8 Monthly variation of Faecal coliform in soil sampled in golf course A [soil irrigated with freshwater (S-FW)] and golf course B [soil irrigated with treated wastewater (S-TW)] studied from February to August 2016

Fig. 9 Monthly variation of *E. coli* in soil sampled in golf course A [soil irrigated with freshwater (S-FW)] and golf course B [soil irrigated with treated wastewater (S-TW)] studied from February to August 2016

0 and 2.05 $\log_{10}$ CFU/g in S-FW and between 0 and 3.28 $\log_{10}$ CFU/g in S-TW. The average contaminations of faecal enterococci in S-FW varied from 0 to 1.8 $\log_{10}$ CFU/g, and from 0.73 to 3.88 $\log_{10}$ CFU/g in S-TW (Fig. 10). The highest contaminations of faecal coliform, *E. coli,* and faecal enterococci was recorded in June, in May, and in June, respectively, for S-FW, and in June, in July, and in July, respectively, for S-TW. The low abundance of faecal coliform and faecal enterococci was detected in February and in March, respectively, for S-FW and S-TW.

The bacteriological contamination in the turfgrass of the studied golf courses was evaluated by counting the faecal coliform (Fig. 11), *E. coli* (Fig. 12), and faecal enterococci (Fig. 13). For turfgrass of golf course A (T-FW), the range values of faecal coliform contamination were 2.97 (May) to 7.22 $\log_{10}$ CFU/g (June), 0 (March) to 2.21 $\log_{10}$ CFU/g (February) for *E. coli*, and 1.44 (May) to 3.18 $\log_{10}$ CFU/g (June) for faecal enterococci. The values concentration of faecal coliform, *E. coli,* and faecal enterococci found in turfgrass samples of golf course B (T-TW) were varying from a minimum of 3.43 (February) to a maximum of 6.35 (August), from 0 (March) to 2.22 $\log_{10}$ CFU/g (May) and from 1.81 (March) to 4.97 $\log_{10}$ CFU/g (July), respectively.

The effect of water type on soil and turfgrass bacteriological quality was tested using the Statistica v6.1 by StatSoft. To determine whether there were significant difference in the contamination levels of the two golf courses. Measured data for each of the faecal contamination indicators were statistically analysed using ANOVA (Table 4). The statistical analysis indicates no significant difference in the faecal coliform and *E. coli* concentration of soil and turfgrass (Table 4). Chevremont et al. (2013) reported that the number of faecal indicators in soil watered with UV-LED-treated wastewater did not differ significantly from soil watered with potable water. Gatta et al. (2015) also have not found a significant difference in the level of faecal coliform in soil and tomato plant irrigated with FW and treated wastewater. However,

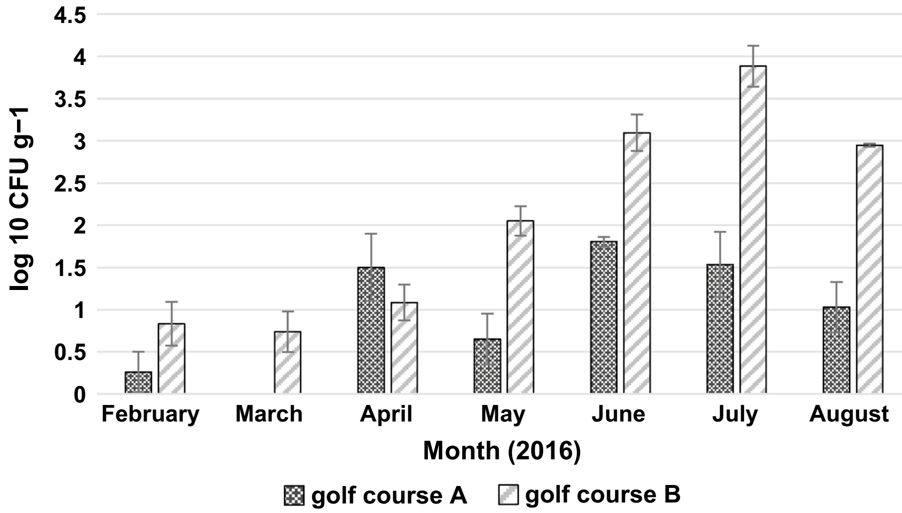

Fig. 10 Monthly variation of faecal enterococci in soil sampled in golf course A [soil irrigated with freshwater (S-FW)] and golf course B [soil irrigated with treated wastewater (S-TW)] studied from February to August 2016

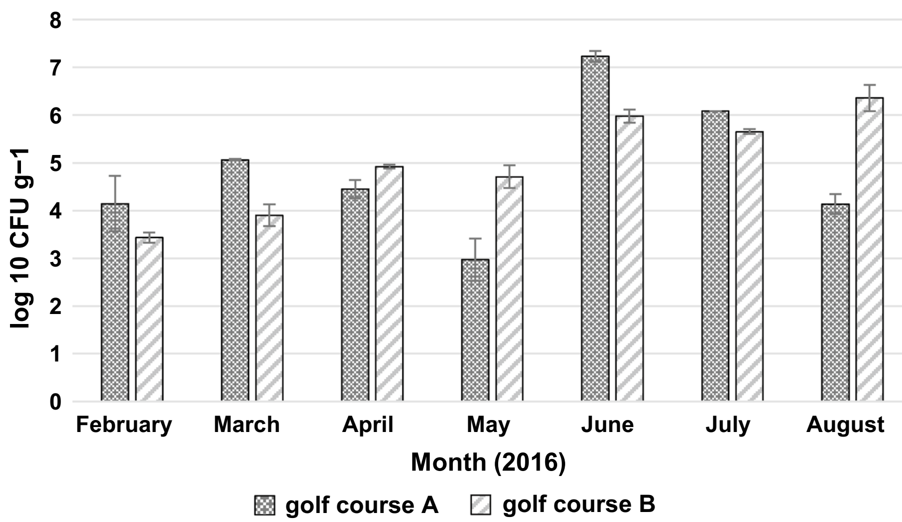

Fig. 11 Monthly variation of faecal coliform in turfgrass sampled in golf course A [turfgrass irrigated with freshwater (T-FW)] and golf course B [turfgrass irrigated with treated wastewater (T-TW)] studied from February to August 2016

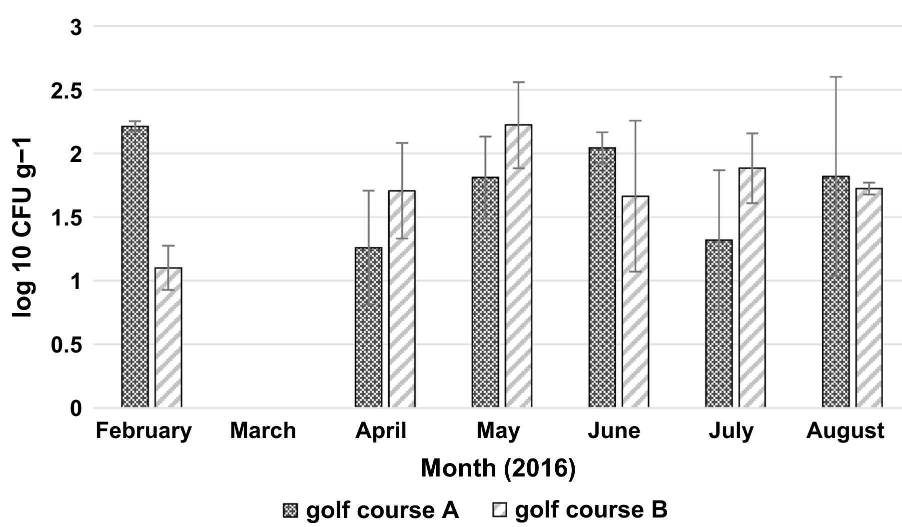

Fig. 12 Monthly variation of *E. coli* in turfgrass sampled in golf course A [turfgrass irrigated with freshwater (T-FW)] and golf course B [turfgrass irrigated with treated wastewater (T-TW)] studied from February to August 2016

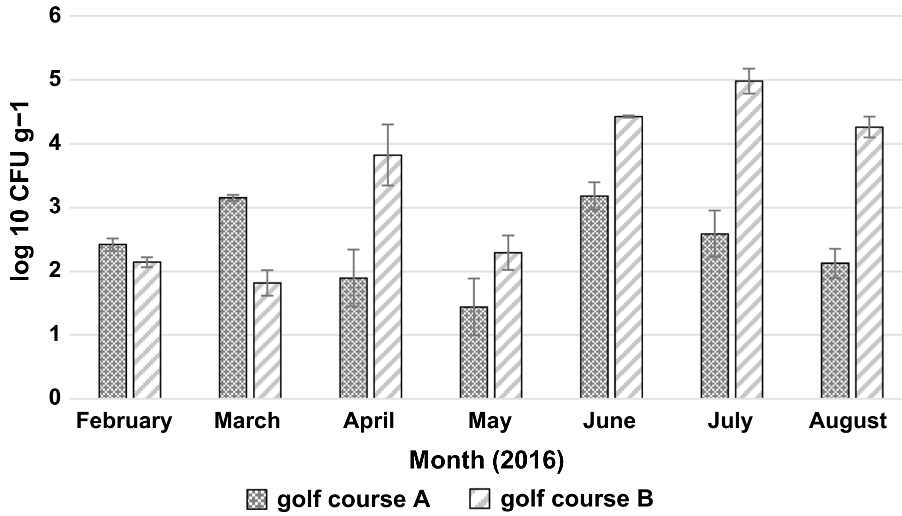

Fig. 13 Monthly variation of faecal enterococci in turfgrass sampled in golf course A [turfgrass irrigated with freshwater (T-FW)] and golf course B [turfgrass irrigated with treated wastewater (T-TW)] studied from February to August 2016

Table 4 Descriptive statistics of the faecal indicators in the soil and turfgrass samples according to the UV-TW and FW irrigation

Bacteriological indicators	Water irrigation used		Significance
	Freshwater	Treated wastewater	
Turfgrass (log10 CFU/g)			
Faecal coliform	4.86 ± (1.4)	4.99 ± (1.07)	ns
Faecal enterococci	2.4 ± (0.64)	3.39 ± (1.27)	s**
E. coli	1.49 ± (0.77	1.47 ± (0.72)	ns
Soil (log10 CFU/g)			
Faecal coliform	4.32 ± (0.77)	4.67 ± (1.32)	ns
Faecal enterococci	0.96 ± (0.68)	2.09 ± (1.25)	s***
E. coli	0.91 ± (0.81)	0.82 ± (1.26)	ns

ns not significant, s significant, $**p \leq 0.01$; $***p \leq 0.001$

a significant difference was observed in the faecal enterococci contamination of soil and turfgrass (Table 4). These findings were similar to those of Hidri et al. (2013), who assessed soil irrigated with freshwater and with treated wastewater. The faecal contamination detected in S-FW and T-FW was probably due to the occasional contamination. Many studies suggest other factors as sources of faecal contamination of the environment (Venglovsky et al. 2006; Palese et al. 2009).

Conclusion

The reuse of treated wastewater continues to increase, especially in arid and semi-arid areas. This water resource represents interesting alternative for agriculture. However, environmental and sanitary considerations should be considered when applying reuse. The results obtained in this study have revealed many interesting aspects: (1) The conventional tertiary treatment adopted in M'zar wastewater treatment plant that seems to be effective to produce treated wastewater meets the Moroccan Standards in terms of faecal coliform. However, considering that in one treated wastewater sample the faecal coliform concentration was above current threshold, the UV treatment must be well managed. (2) Storage method of water coming from the wastewater treatment plant could cause an increase in the faecal pollution of irrigation water. (3) *Faecal* bacterial contamination of the turfgrass and soil is associated with the bacteriological quality of the treated wastewater and environmental conditions related to the golf courses studied. These results are encouraging, even though they are based on a short period of observation. Others studies must be planned for a long period to determine the effects in the same experimental conditions.

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